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A 64 MVA 220 kV transformer for Finland, being shipped at London Docks

(See article entitled "Large 220 kV Transformers for Finland" on page 21.)

Standardization and Simplification in the Electrical Industry, and an Organization for Internal Standardization in a Large Manufacturing Company

By J. T. MOORE, B.Sc., A.R.T.C., M.I.E.E., A.M.I.C.E., A.M.I.Mech.E., A.M.I.Mar.E., Chief Engineer, and P. J. DAGLISH, B.Sc., A.M.I.E.E., Deputy Chief Development Engineer.

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Standardization, as a word, is often grossly misapplied, and as a subject it is much abused or alternatively extolled to excess, or even just simply condemned as leading to inevitable stagnation. It is probably one of the most controversial, in its particular applications, of all subjects to-day, but it is not proposed in this article to enter too deeply into the pros and cons of standardization on any particular class of equipment. Instead it is proposed to deal with the subject broadly in the hope that the advantages, the disadvantages, the difficulties of application in many cases and the tremendous advances already made, may be more widely appreciated, and that from this understanding standardization may be even more widely applied in the future.

Two most valuable reports on standardization have recently been published, namely the " Report of the 'Lemon' Committee for Standardization of Engineering Products," and the Report of the Anglo-American Council on Productivity on " Simplification in Industry." In each of these Reports the broad term Standardization is more closely defined under the three aspects: Standardization, Simplification and Specialisation. The respective definitions in the two Reports are almost identical, and in the simplest terms are defined as follows:

Standardization: Standardization is the process of organizing agreement on a standard for a particular product, range of products, or procedure, and the application of that standard. A standard is a definition with reference to performance, quality, composition, dimensions or method of manufacture or testing, and may be on a Company, Industry, National or International basis.

Simplification: Simplification is the process of reducing the number of types and varieties of products made or called for within a definite range.

Specialization: Specialization is the process whereby particular firms concentrate on the manufacture of a limited number of products or types of products.

Both these extremely important documents stress the need for the creation of a separate standardization organization in all individual companies, which would be under the whole-time control of a senior official. In particular, the following recommendations of the ' Lemon ' Report should be noted:

> Within each firm or wider organization dealing with standardization work, a senior official should be charged with the responsibility for all standardization and simplification activities.
>
> Individual firms should be urged to extend the practice of compiling standard books covering the standard and simplified products selected for production or use in their own organizations.
>
> In spite of the difficulties referred to, we believe that many sections of the industry would greatly benefit from an immediate increase of effort on standardization and related work. Such activity should be treated with the attention which its importance merits, and we consider that it should be made the responsibility of a senior

officer and—where possible—a whole-time standards engineer on the technical staff of each manufacturing organization. The scale of effort will, of course, depend on the operations involved, but sufficient staff should be allocated to ensure that the work is expeditiously carried out, and that it receives the full support of management.

This article shows how the recommendations of these two reports can be fulfilled, and describes the structure, functions, and activities of the standards engineering department of a typical large manufacturing company. It also shows how the benefits predicted by the ' Lemon ' Report are being fully realised in practice, although it is recognized that the major profits will not be visible until such an organization has been running for a number of years.

Standardization and simplification, whilst being separate processes, are frequently closely linked in practice, and, as the second of the above Reports points out, after reduction in variety—*i.e.* simplification—has been carried out, there is often an opportunity for standardization of the resultant range. Conversely, when standardization of a range of products is being considered, it may become evident that some degree of simplification is needed.

An engineer is widely defined as one who can do for a shilling what anyone else can do for five shillings. Similarly, the engineer, by a measure of standardization, can so canalise effort that he can vastly improve on previous output. This, however, would not necessarily be any reflection on his predecessor who, most probably, was obliged to strive continuously to meet innumerable special and possibly not unreasonable requests of purchasers. And therein lies the whole success or failure of any standardization—the purchaser, *i.e.* the user, must be prepared to accept it. Without the co-operation and support of the user in the broadest aspect, standardization can seldom be achieved, and when in such cases it is obtained, as often as not it fails dismally to give the required result. In effect then, standardization, to be successful, must be a joint effort of user and manufacturer. This point cannot be stressed too strongly, as failure to appreciate it is the direct cause of much misinformed criticism not only of standardization but also of the lack of it.

What do we mean by standardization? The popular concept is that of the same article made widely, nationally and even internationally, or of similar articles, largely interchangeable, made to fulfil identical functions; but that in itself is only a comparatively small field of standardization. The field extends from the raw material, through its initial processing, through the main process of manufacture to its incorporation in some piece of apparatus or equipment; through the manufacture and assembly of complete apparatus, equipment or machinery, designed if necessary to meet standardized requirements; through to the user and back again to the manufacturer for the supply of interchangeable spares and components. Without some measure of standardization, if only within the manufacturer's own works, the results can lead not only to complete chaos, with resultant delay, irritation and waste of money, but also—of even greater importance to-day—to waste of man-hours. Standardization thus resolves itself into a simple economic problem—that of how to obtain more cheaply (both in money and man-hours), more quickly and with speedier service facilities, a greater output of equipment capable of meeting the majority of users' needs. The answer can lie largely in getting the maximum of repetition work from standardization and simplification, inside the factory, or outside in standardized user requirements, or both, and the minimum of special designs occupying, in relation to output, a disproportionate number of man-hours in the design department, drawing-office or shops.

To-day, this striving for standardization and simplification, and consequent greater output with available man-power, has become a most important weapon in the national fight for existence as a major power and the preservation and improvement of the standard of living in this country. It is widely recognized that more must be produced to enable more to be imported, and with limited man-power the only way is by increasing the output per man, and by that is meant every man—not just the man in the shops. Standardization and simplification, including specialization, while not being by any means the sole answer, can be of tremendous help. On the other hand it is equally recognized that standardization, if applied too tightly or too quickly, can so limit progress that design becomes moribund and the initiative to

improve is lost. Thus every problem of standardization, simplification or specialization resolves itself into the simple questions: how far can it be taken; how far should it be taken now, in particular; and what safeguards are necessary to ensure continued progress technically and commercially ?

STANDARDIZATION BETWEEN MANUFACTURER AND USER

This is the aspect of the subject of standardization which is most in the public eye. As such, it comes in for much controversy between, on the one hand, those in favour of standardization as a cure for all present-day evils, and on the other hand, those with an excess of caution who see in over-much standardization the end of progress and the end of our reign as the leaders of engineering advances. Obviously neither side is entirely right, and with our national ability to effect a satisfactory compromise, tremendous advances have been made in the agreement between manufacturer and user upon satisfactory standards, while still leaving the way clear for further development.

Such agreed standards, however, are not obtained without hard work, sometimes over a very long time, on the part of the industry's representatives on the many committees regularly meeting to thrash out difficulties and evolve new standards, which, as mentioned previously, must be acceptable to all sides of industry, including in many cases the overseas user, before they are put into effect.

Typical of the work involved and the tremendous scope of the investigations, the British Electrical and Allied Manufacturers Association (B.E.A.M.A.) has some 40 technical committees considering the standardization of various products. Their work results in complete draft specifications being submitted for consideration by the committees of the British Standards Institution. Also, in reverse, these committees examine and advise on draft standard specifications submitted by the B.S.I. for comment.

The B.S.I., as the centre of all standardization, has a tremendous number of technical committees functioning on all manner of subjects, and every section of industry and engineering thought, including the senior engineering Institutions, is represented on these committees. As an example of how much effort and time are devoted to this work by the electrical industry alone, over 1,300 expert representatives of firms which are members of the B.E.A.M.A. serve on over 400 B.S.I. committees. Add to that the correspondingly large number of representatives attending these committees from the users, such as the British Electricity Authority, the National Coal Board, the Railway Executive, the steel industry, the chemical industry, etc., and some idea can be obtained of the effort being devoted to the standardization of engineering products.

In passing, it is interesting to note that in the 'Lemon' Committee's Report, appreciation is expressed of the work which the B.S.I. has carried out in the past and which has been on an ever-increasing scale. Moreover, the evidence which the committee examined shows that this country has been second to none in the preparation of national standards. The committee are also agreed that the B.S.I. is the appropriate body to co-ordinate the views of the various interests concerned in drawing up standards on a national basis and, in particular, that national standards can best be evolved by the co-ordination of manufacturers and users, centred in the B.S.I. They also indicate their belief that the general methods which have been employed by the B.S.I. are fundamentally sound, although they add that its staff and facilities must be strengthened and extended if it is to play its proper part in the work which now has to be handled.

While B.S.I. standards are of tremendous value in the home market, the fact cannot be ignored that this country is primarily an exporting nation, and B.S.I. standards must therefore help and not hinder the country's export trade. For this reason the B.S.I., the manufacturers and the users, through the British National Committee, take part in the similar work of the International Electrotechnical Commission, and thus ensure that both home and overseas standardization have no adverse effect on export trade. In the case of the electrical industry, many B.S.I. specifications have been drawn up as a result of this work, so that whilst reducing the variety of ratings, types and designs

to a minimum, at the same time they avoid the fixation and eventual stagnation of design which can result from too rigid standards, particularly on dimensions.

This policy of creating standards, which leaves the way open for further research and development, is undoubtedly right, as is evidenced by the country's export trade in electrical goods. In 1938 the electrical manufacturing industry became the largest exporter of electrical goods in the world, and in 1948 it had doubled the quantity exported in 1938. That result would not have been achieved without the standardization already effected, but much more will be possible with still more standardization and, where possible without detriment to progress, the adoption of dimensional standards.

This subject of dimensional standards is undoubtedly the most controversial feature of standardization. It is widely recognized that dimensional standards can very often constrain design and retard development. While certain dimensional standards of a particular article might suit one maker's design, another maker might be in a position to supply, for the same duty, a much smaller article, and would be required to depreciate his design to make it comply with the proposed dimensional standards. Equally, the reverse might apply. A compromise might suit no one, but nevertheless the effort may have to be made to arrive at acceptable dimensional standards if by so doing an increase can be made in the output of the industry of the particular article, and in the exports of it, all without increase and preferably with a decrease of the man-hours per article.

Although dimensional standards, while they might be an advantage in certain respects, are not absolutely essential for many of the products of the electrical industry, there are also many products in which interchangeability is of paramount importance.

For example, the following are typical products for which dimensional standards have been prepared or are being finalized :—

House service meters.
Electric cooker hot-plates.
Electric-fire elements.
Cooker control units.
Bolted flameproof cable couplers.
Cable boxes for switchgear and transformers.
Fractional-horse-power motors.
Cartridge fuses for domestic installations.
Tumbler switches for domestic and similar premises.
Universal domestic plug-and-socket outlets.

Many more products might be mentioned where dimensional standards could be adopted with advantage, but in the electrical industry as a whole, where the results of research and development often enable improvements to be introduced whereby the same performance can be obtained in smaller dimensions, experience shows that it is better to defer the use of dimensional standards in favour of other forms of standardization or simplification until both users and manufacturers agree that further development of the particular product is likely to be small, and that in the overall interest its development can be allowed to remain static for a number of years. The general policy in the electrical industry, therefore, is to use over as wide a field as possible standards of merit and performance in preference to dimensional standards.

Some typical examples will illustrate how this policy operates in practice.

Generating Plant

In this class of equipment the wide variations in users' requirements both at home and overseas, the tremendous field available for research and development, and the steadily increasing size of individual units, make the laying down of comprehensive standards for types, ratings and performance of all generating plant virtually an impossibility. On the other hand, it is possible to lay down preferred ratings and, in a limited number of sizes, operating steam conditions. B.S.132 : 1930 lists preferred ratings up to 100,000 kW (but without tying ratings to speeds) and is at present under revision to bring it up to date. In addition, with the co-operation and full support of users and manufacturers, the Ministry of Supply in 1947 issued Statutory Rules and Orders No. 2386 which limits to two sizes, 30,000 kW and 60,000 kW at 3,000 r.p.m., the generating sets which may be produced for use in this country unless otherwise agreed with the Ministry of Supply and excepting overseas contracts and marine applications. For these two sizes the Order specifies the speed, 3,000 r.p.m., the initial steam conditions and final

feed-water temperature, but to meet the varying cooling-water temperature conditions in this country it leaves the vacuum unspecified. All conditions affecting the design of the turbine are therefore not tied up, and more than one design of turbine could be supplied within the terms of the Order, but with a good spirit of co-operation between users and manufacturers the number of turbines in each rating is virtually limited to two; one high-vacuum, for use on sea coasts and river estuaries, and the other medium-vacuum, for use in cooling tower stations. That is a very great advance on conditions before the issue of the Order, when it was not unusual for a manufacturer to have as many as six or seven different designs of 30,000 kW turbines in production at the same time, to say nothing of all the other ratings from 30,000 kW upwards—40,000, 45,000 and 50,000 kW and odd ratings such as 31,500 kW, 32,000 kW, 51,500 kW, 52,500 kW, etc.

But the important point of the Order lies in the fact that under licence from the Ministry any size or design of turbine can be produced, and licences are granted for a predetermined proportion of special machines of an advanced or experimental design, thus ensuring the continuance of research and development. This Order has now been included as an addendum to B.S. 132.

So far, the electrical conditions of the alternators for the 30,000 and 60,000 kW ratings have not been similarly laid down, but preferred voltages and power factors have been decided by the British Electricity Authority for their own requirements, and again the manufacturers have gained the benefits of this measure of standardization by the great reduction in the numbers of different designs required.

In like manner, many of the Dominions and other overseas users have expressed their readiness to specify the S.R. and O. Standards, with resultant advantages in the country's production of generating plant.

As a further instance of what can be achieved by the issue of preferred standards for generating plant, the users and manufacturers in the United States, through two of their engineering institutions, agreed upon a set of preferred standards for their 60-c/s generating units of 11,500 kW, 15,000 kW, 20,000 kW, 30,000 kW and 60,000 kW, all at 3,600 r.p.m. Since the agreement on these preferred standards in 1945, the majority of sets ordered have been to the preferred standards but not to the exclusion of more advanced designs and higher ratings, of which many have been produced up to 100,000 kW and utilizing initial steam conditions (both pressure and temperature) much higher than specified for the standard units. The electrical industry in the United States has thus benefited greatly from the adoption of preferred standards, while continuing an extensive programme of development and research.

Transformers

Much has already been done in establishing preferred ratings up to all but the very largest sizes, and recently, with the advent of the British Electricity Authority as the principal user in this country, further standardization proposals have been formulated by the manufacturers for consideration by the B.E.A. These have been prepared in the interests of interchangeability and apply to rural distribution transformers up to 100 kVA and 33 kV, and to substation transformers of 100-1,000 kVA and up to 33 kV.

Further, in order to line up and complement the Order for standard generating units of 30,000 and 60,000 kW ratings, corresponding standard ratings for step-up generator transformers for coupling direct to the generator terminals have been laid down by the B.E.A., and in each case, for the particular size, preferred voltage-ratios have also been established. These preferred standard-ratings and voltage-ratios will very materially assist in a large measure of standardization on both alternators and generator transformers for the two standard sizes of 30,000 and 60,000 kW sets.

Motors

While a draft specification has been prepared for dimensional standards for fractional-horse-power motors to provide interchangeability of different makes, similar standardization for larger motors (over 1 h.p.) involves an entirely different and much more complex problem on account of the large number of types, sizes and characteristics required to meet the great variety in users' requirements, both at home and overseas. The leading

industrial motor manufacturers in this country have held a number of meetings between themselves and with all the major user organisations to try and establish an industrial motor dimensional standard for outputs up to 20 h.p. This has now been done for totally enclosed fan cooled machines, and a draft has been submitted by the B.E.A.M.A. to the B.S.I., which it is hoped, as a result of the previous consultations, will now be published without further amendments. This draft utilizes the same dimensions as the N.E.M.A. (The National Electrical Manufacturers Association of America), but in view of the fact that the British motor designers produce a much smaller machine than the Americans, all the ratings for a given frame size have been increased one step with a corresponding increase in shaft diameters. The authors are of the opinion that this dimensional standard is a matter of major importance to the industry and would urge the manufacturers to co-operate in implementing it as soon as possible after publication.

STANDARDIZATION WITHIN A MANUFACTURING ORGANIZATION

Within any manufacturing organization there is always some measure of standardization consequent on the general adoption of British Standards, where applicable. Prior to the establishment of the British Engineering Standards Association (now the British Standards Institution), the amount of standardization between manufacturer and user was extremely small—almost negligible—and, as a result, the amount of standardization which could be achieved within a manufacturer's own organization was correspondingly small. At the same time it must be remembered that the electrical industry in the early years of the century was comparatively new, with continuous expansion into new fields and new types of equipment and machinery. This naturally gave rise to a large quantity of new designs, new methods and the use of new materials. It is all the more surprising and gratifying, therefore, that the electrical industry to-day occupies the foremost place of any single British industry in its contribution to standardization, as evidenced by the number of British Standards on electrical engineering. Just over 1,600 British Standards are in use to-day, over 500 of which are contributed by the electrical and mechanical engineering industries, and of this number, more than 300 are electrical engineering standards—approximately 20% of the total.

This result has not been achieved without very considerable effort from all sides of the industry, both manufacturers and users, and a leading part has been taken by the British Electrical and Allied Manufacturers' Association which as far back as 1911 set up its own Standardization Committee. From 1911 to 1916 the B.E.A.M.A. published its own Standard Rules and Specifications, while at the same time it co-operated in the preparation of British Standards. From 1916 this policy of publishing its own specifications was discontinued, as British Standards covering the same ground and prepared in association with the B.E.A.M.A. were becoming available. To-day the B.S.I., with the full support and co-operation of all sides of industry, is pursuing a vast programme of proposed new and revised standards through a multitude of technical committees on which, as many members who serve on one or more will know, are representatives of every section of opinion—manufacturer, user, consultant and technical institution.

With the publication of the first engineering standards, there began, with growing momentum, the introduction of standards in manufacture. Apart altogether from the obvious advantages of as much standardization as possible in materials and processes of manufacture, there was the necessity, as users came to accept British Standards in place of the many different standards existing previously, of manufacturing to the relevant British Standards. To-day the phrase " Manufactured to British Standards " is the hall-mark of performance and reliability in engineering, but it leaves room for each manufacturer to employ his own " know how " and skill to the fullest extent. To be able to substantiate such a statement as " Manufactured to British Standards " requires in any manufacturing organization a degree of control, in fact an organization within an organization, which is quite staggering to anyone not conversant with the details of modern works practice.

It might be imagined that all that should be required is for the designer and the draughtsman

to design the particular article with copies of the relevant British Standards in front of them. Bearing in mind that there are over 500 British Standards with a possible bearing on the particular piece of, let us say, electrical apparatus or machinery, it is necessary to have some section or individual continually keeping in the closest touch with the design team, with the purchasing of raw and finished materials, with the manufacture and finally with the testing of the equipment. Again, British Standards are not the only controlling factors, as they cannot possibly cover all the particular requirements of the user. The designs must comply with all the duty and test requirements of the purchaser, in addition to the broad requirement of compliance with the relevant British Standards, and also with any special Government requirements and safety precautions essential to the particular piece of equipment or its application. As examples of the latter, there are the special requirements for explosion- or fire-proof machinery for use in coal mines or where there are inflammable gases, special precautions to be taken with hydrogen-cooled alternators, precautions to obviate Post Office telephone-line interference, radio interference, etc., or, in general, there is the necessity of avoiding becoming a public nuisance or a public danger.

In any manufacturing organization, therefore, there must be someone, or a department if necessary, responsible for the dissemination throughout the design staff of all British Standards and other standard specifications, revisions, modifications, and also projected standards. Only in this way can the design staff be sure they are designing to the relevant existing and projected standards, while at the same time designing to meet the particular requirements of the user.

The designer's responsibilities, however, in this modern world of more and more output per man, do not end there. At all times he must endeavour so to arrange his design, whether a motor, a switch or a generator, that the basic design can be utilized in a wide variety of forms for different applications. This measure of standardization, or rather simplification, will enable some repetition manufacture to be obtained, even though there may not be any corresponding accepted standard between manufacturer and user. This is such obvious common sense that one may wonder that it is mentioned, but to do just what has been suggested is not always a simple matter and, in addition, the economics of the cost price in relation to the selling price must be taken into account. Nevertheless, much can be done in all works to incorporate the maximum number of standard parts in most designs, and here again the standards engineer or department functions in the preparation of lists of standard parts, both of raw and semi-processed materials and of manufactured parts. With such a list in front of him the designer can incorporate into any new design some stock materials and at least some parts which will not require new jigs and tools for manufacture. It is this class of what may be termed " internal " standardization or simplification that can so materially assist production and which, in the electrical industry at least, has been so successfully tackled on many products. Much, however, still remains to be done in most manufacturing organizations. Typical of the class of product in which such " internal " standardization can be effectively carried out are circuit-breakers—where different types of operation and different busbar arrangements have all to be considered. Similarly on distribution transformers many different arrangements of incoming and outgoing cables and terminals are required to meet the various types of service, and no manufacturer wants to make more basic types than are absolutely necessary. There is no limit to the number of examples which could be given, as all engaged in industry know, and even without agreed standards between manufacturer and user much can be, and is being, done on the foregoing lines in every manufacturing organization.

The designer and draughtsman having carried out their part, the manufacture of the article presents still further fields of standardization. Once the best method of manufacturing an article or part of an equipment or machine has been determined, having regard to the quantities involved, it would obviously be wrong not to standardize on the method. This would follow almost automatically in a small organization where everyone more or less knows what everyone else is doing, but in the larger organization, particularly where a number of different factories—and factories overseas—are manufacturing similar articles, some

system is necessary for preparing process specifications and ensuring that they are worked to throughout the organization. Naturally, methods may change from time to time, and the system must be capable of picking up the changes, when proved beneficial, and revising the relevant process specifications. Such process specifications ensure standardized methods throughout manufacture, with consequent saving of planning time and instruction time in the shops. Again, it is a job for the standards engineer or department, and much time can be saved and quality maintained by the use of such " internal " standardization.

Similarly, the introduction of standardization on the purchasing of materials leads to very great economy in time, while simultaneously introducing a necessary element of control. In particular, different qualities of insulating materials, varnishes and paints, for example, required for different applications, must comply in every case with particular specification requirements, and this can all be tied up by the standards engineer in co-operation with the purchasing and inspection departments.

In all the ways mentioned, the manufacturing industry, and particularly the electrical industry, is energetically standardizing wherever possible within its own factories, and a still further degree of standardization and simplification is becoming possible on repetitive articles with a minimum of variation in design, by the increasing acceptance of standards agreed between manufacturer and user.

ECONOMIC JUSTIFICATION OF INTERNAL STANDARDIZATION

Much has been written about the economic argument in favour of a comprehensive standardization policy, and as all the major points are dealt with fully in the ' Lemon ' Report, both for and against, it is not intended to repeat them here. It should be noted that in the opinion of the Committee there is an overwhelming economic case in favour of extensive standardization, even at the cost of high initial expenditure. In this connection, when discussing the importance of the objective, the Committee state:—

> There can be no question that unnecessary variety of product at any stage of manufacture lowers efficiency. The loss is not confined to any one stage of manufacture, but extends to the supply of raw materials and components. It also applies to all phases of distribution and to the ultimate user. The latter is faced not only with the resulting higher prices but often with related problems of non-interchangeability, delay in obtaining non-standard spare parts, increased stocks, and unnecessary design and administrative work.

A common criticism directed against the arguments justifying a standardization policy on economic grounds is that all the savings postulated are hypothetical in nature and depend on imponderables. This is true to the extent that methods of accountancy do not allow of the accurate measurement of some of these monetary savings, but that they are there, and are undoubtedly of some magnitude, cannot be denied. In addition, there are numerous concrete cases which can be cited where the actual savings are not only visible but sometimes run into thousands of pounds in a single instance.

An indication of these imponderables, with a few concrete examples for some of the different types of standards, is given below.

Shop Processes.—A good set of shop-process specifications properly used will reduce major scrap to a fraction. In the case of large castings or fabricated structures, this may in a single instance represent a saving of many thousands of pounds.

Materials.—A proper choice of materials, made in consultation with suppliers, may often result in a cheaper article which will still give the desired result. A change of an alloy steel to one of the En series specified in B.S.970 : 1947 resulted in the saving of £12 10s. a ton, the annual consumption being about 200 tons. Furthermore, it is estimated that when the materials catalogue is functioning fully it will cut down varieties of raw material by 60%, with an approximate saving in stores area and stock in hand of 40%.

Components.—This field probably represents the biggest saving of all. One component—a casting—recently standardized used to be detailed every time it was required. Apart from the drawing-office time involved, a new pattern costing approximately £50 had to be made every time, and several hundred were used a year. Both drawing-office time and pattern cost have now been eliminated. Suitable choice of dimensions in relation to the

raw material available can often save whole machining operations, and standardization on an adequate scale will permit batch production of components on a semi-mass-production basis.

These few instances can be multiplied many times over, causing an aggregate saving over the years of a considerable sum. If the savings resulting from the many imponderables such as reduced drawing-office time, quicker and more accurate inspection, rapid instruction of new personnel and a host of other small items all making for smoother and more efficient administration are also taken into account, it will be readily appreciated that the monetary savings of a standards organization can greatly exceed the cost of running it.

Stress has been laid on the economic aspect because, too often, this is either ignored or misunderstood. A standards organization is frequently accepted as a convenient luxury, to be dispensed with in hard times. Nothing could be further from the truth. Properly run, it can be the biggest single money-saving factor in any manufacturing concern, particularly in the electrical industry, where design and production problems are so very complex.

TYPE OF STANDARDS ORGANIZATION

Most large electrical manufacturing companies have had some form of internal standardization organization for a number of years, particularly those that consist of a number of separate works that were formerly independent companies.

These standards organizations were usually in one of two forms, with small variations. One form consisted of a voluntary association of departments —usually drawing offices—to produce between themselves such common standards as appeared feasible. One individual, either by accident or design, would be appointed to carry out the necessary co-ordination, and printing and distribution, etc., would be provided by existing facilities. The second form was a standards committee—again usually consisting of drawing-office personnel—which by means of regular meetings produced common standards which those departments represented were committed to adopt. Usually, one of these departments would take on the secretarial, printing and distribution work.

Admirable as these arrangements were for, say, 20 years ago, they suffer from a number of disadvantages under present-day conditions, some of which form insuperable obstacles to an active comprehensive standardization programme.

To be successfully applied, all forms of standardization involve a degree of discipline. As both of the methods outlined were usually voluntary associations, they were not subject to managerial control and were therefore without active managerial backing. Consequently, except in those departments immediately concerned, there was no means of enforcing any of the standards evolved.

Most of the individuals concerned were usually senior men, often chief draughtsmen, with departmental responsibilities of their own. As a result, with the extreme pressure of work to which everyone is subject under modern conditions, either their department or standardization suffered ; not unnaturally, it was usually the latter.

As these committees were usually composed of men associated with drawing offices, the majority of standards produced were for use in the drawing office. Furthermore, only a proportion of the products which the company manufactured were usually represented, so that, even from the drawing-office standpoint alone, the field was not fully covered. Present-day conditions call for standards covering the entire manufacturing field. Only by consulting departments with specialized knowledge in design, production, purchasing and inspection, as well as the drawing offices, can satisfactory practical standards be prepared.

To keep any standards organization alive and active an efficient distribution and maintenance service is essential. This involves a whole-time and competent clerical staff which would not be available in any section with departmental responsibilities.

Consequently the conclusion is to be drawn that the only satisfactory organization capable of meeting present-day needs is a separate standards engineering department, responsible to one of the chief executives and receiving active support from all works managements. It should be staffed by engineers with no departmental responsibilities and be in no way dependent on outside facilities. It should have its own printing and reproduction

equipment and run its own distribution and maintenance services.

THE STANDARDS ENGINEERING DEPARTMENT

The form which any standards engineering department should take will, of course, be largely dependent upon the type of manufacturing organization concerned. This article considers here a large company consisting of a number of factories geographically separated, with autonomous government so far as all production matters are concerned, but subject to co-ordination in matters of company policy regarding design, development, sales, etc., carried out by chief executives from the head office. This form of organization may well be taken as typical of a number of the larger electrical manufacturing companies, and is of course similar to that of The English Electric Company.

Terms of Reference

If the argument in favour of the creation of a separate standards engineering department is accepted, it is necessary to define the terms of reference before considering its composition. These may be summarized as follows:—

Functional Responsibilities.—The ultimate aim of standardization is to exercise control of the design and performance of the finished product by the most economical means available; its function is therefore primarily an engineering one. Consequently, the standards engineering department should be responsible for all matters affecting internal standardization policy direct to the chief engineer (or technical director) and be subject only to his control.

Co-ordination.—In general, all standards affect the production and planning departments as well as the design departments, whilst in the case of purchase specifications, the purchasing department is also concerned. In addition, it is frequently necessary to seek the advice of the research and metallurgical departments, works laboratories and similar consultant sections. The department must therefore have access to all these at all levels, to ensure effective co-ordination.

Form of Standards.—The standards engineering department is responsible for the production of all standards, so that it must therefore be entirely responsible for the form these standards shall take, giving due consideration to clarity, durability and cost. It must also decide which specialist departments are ultimately responsible for the technical contents.

The Contents of Standards.—The most important fundamental rule of all standards is that they should be voluntary. The department should therefore have no power to decide what the technical requirements of any standard should be, and these should be arrived at by a large majority agreement between the specialist departments concerned.

Enforcement of Standards.—An unused standard is so much wasted paper and money. The department must therefore ensure—in conjunction with the inspection department and drawing offices—that all standards are being used throughout the company, within the limits of their application. If a standard is not used because it is no longer applicable, it must be revised with the minimum delay. Standards must never be allowed to hinder development, and the co-operation of the inspection department should ensure rapid amendments and prevent unnecessary bottlenecks caused by over-enthusiasm.

Organization of the Department

Let consideration now be given to how such a department should be organized to enable it to fulfil its functions under the above terms of reference in the most economical and efficient manner.

Manager of the Department

The manager of the department should be given full authority on all matters affecting internal standardization policy, and he should be of a standing to enable him to discuss policy with chief executives and works managers on terms of equality. He should be made responsible only to the chief engineer (or technical director) and be given financial control of all expenditure within certain prescribed limits. Any standard issued under his authority should be mandatory within its specified application. He should be a company official with no responsibilities to any particular works.

Central Office

As it is essential for all standards to be of company-wide application, so far as is possible, and for the variety of standards to be kept to a practical minimum, it is clear that the main portion of the staff should be located in a central office serving all works.

This office should be divided into three main sections dealing, respectively, with the standardization of components, material standards and specifications, each in the charge of a senior standards engineer. In addition, there must be a clerical section of sufficient size to provide adequate distribution, maintenance and typing facilities, and able to carry out all printing and reproduction work for the whole department. Adequate printing and photographic equipment must be provided, including half-tone apparatus. A few good draughtsmen and tracers are necessary for preparing drawings and sketches. Since the value of good-quality standards cannot be overemphasized, this clerical and reproduction section is one of the most important in the department. Savings in capital expenditure involving inadequate or unsuitable equipment will prove false economy in the long run. High-quality reproductions must be made as a commercial article at a commercial price.

Works Offices

In addition to the overall company standardization referred to above, each works has its own problems, particularly regarding manufacturing standards such as process specifications. Furthermore, before any company standard can be established, a mass of detailed information is required from each works in the organization. Therefore, a works office should be set up in each manufacturing centre of the company, and it should be in the charge of a works standards engineer who in turn would be under the general technical direction of the manager of the standards engineering department and must provide the necessary information for the central office to fulfil the standardization programme. His prime responsibility, however, is to serve the needs of his own works, and he should therefore be made administratively responsible directly to the management of that works, whose active backing he must receive if he is to function efficiently.

The appointment of the works standards engineer is a vital one, for, although the bulk of the preparation of standards is done by the central office, it is upon him that their effective application in design and drawing offices, and on the shop floor, depends. He must work in the closest collaboration with all design, planning and production departments and ensure that all standards are active and up to date. He should have a small staff of junior standards engineers and a clerical staff which is adequate to deal with local distribution and maintenance.

He will prepare all standards that are for local use, but will send them to the central office for numbering, indexing and editing before reproduction. They will then be distributed in bulk by the central office to all works standards engineers, who will decide their own local circulation. By this means a uniform quality is maintained, economy in equipment is assured and control exercised by a comprehensive central-indexing system, thus preventing duplication of effort.

Number and Type of Staff

The total number of standards engineers employed is clearly a function of the number of factories and variety of products rather than the total size of the organization concerned, but it is impossible to lay down any arbitrary rule. Sufficient numbers must be employed to make the preparation of standards a reasonably rapid operation, but a balance must be drawn against over-production.

For the type of organization being considered, the specifications and material sections of the central office should have a minimum of three or four engineers, whilst the component section should have at least six, the majority of whom should be draughtsmen, both electrical and mechanical. A clerical and typing staff of at least twelve will be required. Each works office will probably require three to six engineers, according to its size and the variety of its products.

The job of a standards engineer is not an easy one, and careful thought should be given to the selection of personnel, particularly for the senior appointments. It is extremely hard work and

often encounters considerable opposition. In general, young men should be chosen who possess a genuine enthusiasm which will enable them to ride the inevitable disappointments, frustration and delays which occur in this type of work. They must be of a mentality which will make them seek work in the drawing offices and on the shop floor rather than wait for it to come to them. A sound general knowledge of both mechanical and electrical engineering should be combined with a personality which will enable them to hold friendly relations with men older and more experienced than themselves and to meet them on their own ground. Generally speaking, they should be men in whom personality and technical ability are combined in the ratio 3 : 2, but, above all, a standards engineer must possess a large measure of drive and initiative.

Apprentices

It is the considered view of the authors that all graduate and student apprentices should spend a period in the works office of the standards engineering department towards the end of their training when they should be employed in the preparation of manufacturing standards. Provided they are kept for a minimum period of two or, preferably, three months, with proper supervision they can be of material assistance in this work. Apart from this, however, the apprentice himself gains the following advantages:—

(*a*) He learns certain processes in far greater detail than ever he would when employed in a production department.

(*b*) He sees manufacturing problems presented in an entirely new and much broader light.

(*c*) He learns something of the administrative structure of both the works and the company.

(*d*) He is grounded in the art of obtaining information from other men.

(*e*) Above all, he will learn the real purpose of standardization and see it in operation, with the result that, in whatever department he may be located in later life, he will remember and apply standardization principles.

It has been the experience of the authors that the right type of apprentice is a definite—if temporary—asset and that he leaves the department completely convinced of the worth of the work he has been doing. The real benefits of this training will be apparent in five or ten years' time when, in addition, a potential source of standards engineers will have been created.

Relationship with Other Departments

To appreciate properly the function of the standards engineering department, it is necessary to consider its relations with other departments with which it is concerned and the terms of reference of those departments.

A proper understanding of the terms of reference and their relationship to each individual standard is most important and prevents overlapping of comments, with the consequent delays. Furthermore, it ensures that each department carries its proper share of responsibility. It must be appreciated that over the years these responsibilities have changed. Design and drawing offices no longer decide on methods of manufacture or carry out their own inspection. A heavy responsibility rests on planning and production departments to fulfil the designer's requirements by the most economical means available, and the engineer must adapt his designs to modern production methods. Consequently, a very close co-operation between design, planning and production departments is called for, and the preparation of standards provides the ideal meeting ground. The standards engineer, who has no departmental responsibilities, does the necessary liaison work.

Below are given briefly the terms of reference of those departments with which the standards engineering department is concerned.

Design Departments

The various design departments are responsible for the satisfactory economic design and performance of their products. The word "economic" should be stressed, because designs are not always adaptable to the cheapest production methods. They must therefore use British Standards and company specifications and standards wherever possible, and avoid the use of special materials. This should not be interpreted as an impediment

to development; the contrary is the case, for if standards are properly applied more personnel will be available to work on future designs and the testing and development of prototype models. These, in turn, will form the basis of future standards, and only after the development stage has been passed should the design be examined from the point of view of standardization. If necessary, new standards must then be created, provided that the anticipated production volume justifies such action.

Drawing Offices

Production drawing-offices are responsible for translating the design requirements into specific instructions to the production and planning departments. Not only must the drawing show the dimensions and tolerances accurately, but it must also call for all relevant process and insulation specifications as well as standard materials and components. The drawing is the prime instrument for ensuring that all the relevant specifications and standards are used on the shop floor, and its influence is vital in the implementation of any standardization policy. The whole-hearted co-operation of the production drawing-office is therefore essential.

Planning Department

Most organizations have a planning department, or its equivalent, which organizes and plans, step-by-step, the operations which are required to complete the product or component from the initial casting or machining to the final assembly. This "operation planning" as it is sometimes called, is put on to the appropriate forms and transmitted to the production departments; together with the drawings, these forms provide complete manufacturing information in detail. It is essential that all references to relevant specifications and standards should be entered on these forms, for many process specifications will have no appropriate drawing on which they can be quoted.

The planning department is usually responsible for the provision of plant, equipment, machine tools, etc. Its staff therefore have a vital interest in all manufacturing standards, and should ensure that each process is adequately covered; where possible, they should encourage the standardization of plant between different works to facilitate interchangeability. They should always examine drawings before they are finalized, since small changes in design—even in a single dimension—can substantially reduce the cost of manufacture, and they have a specialized knowledge of the equipment and manufacturing standards available which is seldom possessed by the drawing offices.

Production Departments

These departments are responsible, on the shop floor, for the efficient, speedy and accurate manufacture of the products with the equipment provided, to the instructions of the planning department and within the limits of size on the drawings. Their staffs should ensure that all operators are familiar with relevant process specifications and other manufacturing standards, and they can give valuable advice in their preparation.

Inspection Department

The inspection department is responsible for ensuring that the product is manufactured not only to the drawing requirements but also to any relevant specification, and the inspectors should be empowered to reject any component that has not been made to specification; it is thus essential to ensure that all standards in their hands are correct in every detail. The department is also responsible for ensuring that all material and components received from outside suppliers comply with the appropriate purchase specifications. Thus, it is ultimately the inspection department which ensures the application of all manufacturing and material standards, and its function is a vital one in the chain of events.

The Purchasing Department

The purchasing department is responsible for obtaining all materials and components from outside suppliers. The co-operation of its personnel should therefore be obtained during the preparation of purchase specifications, by circulating the drafts to a selected list of suppliers for comment. A slight alteration to a specification can frequently effect a reduction in price without sacrifice in performance. The department is also responsible for ensuring that adequate stocks of standard components and materials are held and that non-standard stocks are not purchased without the proper authority.

CONSULTANT DEPARTMENTS

The departments so far considered are of a functional nature, but there are others, such as the research, metallurgical and electrical laboratories, which can give valuable assistance and whose advice should be sought where applicable. It must be remembered, however, that they are consultant by nature, and ultimately the responsibility must rest with the " functional " department concerned.

The Relationship with External Standardization Policy

The application of an internal standardization policy cannot be entirely divorced from the corresponding external activities, which are usually carried out by representatives of design departments sitting on various technical committees of the British Electrical and Allied Manufacturers' Association, the British Standards Institution and similar bodies.

There must therefore be co-ordination between the two, and the standards engineering department should be the channel through which all comments on draft national specifications are routed. This is of particular importance for those specifications with which the electrical industry is concerned as a user rather than as a manufacturer. Such specifications may exert considerable influence on the design of standard components or sub-assemblies.

EDUCATION IN STANDARDIZATION

In the past the average engineer has generally regarded standards—apart from B.S.I. design standards—as something peculiar to the drawing office. He has not fully understood the implications of comprehensive standardization, and has regarded it with a certain amount of suspicion.

Standardization can never be applied by compulsion; it must receive full voluntary support from all concerned. The entire technical and production personnel must therefore be so educated that they themselves are convinced of the value of the work that is being done. This is most important in the junior grades, since many of the senior and more responsible men have no need for such conversion. As much has been written on this subject in the Lemon Report, there is no need to enlarge upon it further. The best criterion is results. The standards themselves should be of an obviously high quality, and the financial and other benefits that accrue from them should receive adequate publicity. One method of doing this is to publish periodically some form of standards journal containing topical information. It should be written in an informal style and the simpler principles of propaganda should not be despised. This journal should also contain lists of all new and revised company and national specifications and a list of all standards under preparation in each works of the organization.

THE DIFFERENT FORMS OF STANDARDS

General Conditions

When considering the different forms of standards it should be remembered that they are not new and are all used to some degree in most existing organizations. What is different is the scale on which they are produced and applied and the method of preparation and maintenance.

There are a few general rules applicable to the preparation of all types of standard:—

(i) Each class of standard must have its own easily recognized numbering system which should be as simple and flexible as possible, with ample room for expansion. Attractive as the idea of a self-indexing code may be, it invariably leads to a most unwieldy number and is never understood by anyone except the inventor. Such a code should therefore be energetically resisted.

(ii) The title should be short and clear.

(iii) Each set of standards should have its own index of numbers and titles. A highly efficient index system is most important to ensure the rapid identification of any standard, and these indexes must be kept rigidly up-to-date. There must also be a comprehensive cross-reference index between different types of standards, to assist maintenance and identification.

(iv) The text must be a clear unambiguous instruction, and alternatives should be

avoided. Where an alternative must be given, an order of preference should be stated.

(v) Sketches and drawings must be of high quality and all dimensions should show the correct tolerances. For specifications, three-dimensional sketches are usually preferred and half-tone photographs are often an advantage.

(vi) Each standard should carry full cross-references to other standards to which it is related.

The method of preparation by consultation with the specialist departments has already been discussed, and those departments usually consulted in the preparation of the various types of standards are given below. Specifications should always be signed by the "functional" departments concerned.

Process Specifications

These are instructions to the production department, and show how standard manufacturing processes are to be carried out, what equipment is to be used and what operating conditions should be maintained. Design, planning and production departments are all directly concerned in their preparation and must always be consulted within their respective spheres.

Insulation Specifications

These are a very important and specialized form of process specifications. They control both the material and method of manufacture of insulated conductors, windings, etc. Where there is a separate insulation engineering department, its personnel should be responsible for all the technical information; where no such department exists, a senior standards engineer with the necessary specialist knowledge should be employed.

Purchase Specifications

These are technical specifications giving the full chemical, physical and electrical properties of all materials purchased from outside suppliers, where there is no suitable British Standard. They should also stipulate the inspection conditions and conditions of acceptance, which should be standardized so far as possible. In general, only design departments are responsible for their contents. It is most important that British Standards should be used in their place when possible.

Materials Catalogue

The various volumes of the materials catalogue should list all raw materials stocked by the company. They should be divided into main sections covering iron and steel, non-ferrous metals, insulation, paints and varnishes, industrial fasteners, etc., which are stocked in each works, and then divided into sub-sections for each material specification. These sub-sections should be preceded by a sheet giving the full properties of the material, ordering data, special applications, etc., and subsequent sheets should list all items, with details of where stocked and other relevant information.

The materials sheet is prepared from information received from the purchasing department on stock ordered and the movement of materials, and is simplified into preferred sizes by consultation with the drawing offices. Certain items will be found to have only a limited or specialized demand and should be put into a separate category. No person should be allowed to specify items from this latter category without proper authority, and by this means the large majority will eventually become obsolete and can be deleted.

Standard-part Volumes

These volumes list all standard components in use and, in conjunction with the materials catalogue, undoubtedly give the most remunerative returns. Each sheet should contain a fully dimensioned drawing of the component, together with the material specification and necessary manufacturing information. The different sizes of component, with details of where each is stocked, should then be listed in tabular form. These volumes are prepared mainly in consultation with the design departments and drawing offices, but where a new design is being prepared the planning department should be consulted to facilitate manufacture.

Standard-part sheets should not be confined to single components but extended to sub-assemblies such as relays, contactors, brush-gear, oil pumps,

etc., which can be manufactured by batch production and then stocked.

Manuals

Manuals are not in themselves standards in the accepted sense of the word, but they form a convenient means of providing general or specialized technical data and of recording design or administrative procedure, etc., all of which contribute to making a smooth administrative machine and accelerate the training of new personnel.

They must be prepared in a palatable form and give easy reference. Typical examples of manuals are those covering general engineering data, insulation, welding practice, testing, drawing-office practice, contract procedure and design calculations.

Maintenance of Standard Sheets

The importance of an efficient and speedy maintenance service cannot be overstated, as this, more than any other factor, keeps each standard alive. The ideal should be to keep every sheet not more than two months out of date; confidence will then be instilled into all users of standards. In the past, standards have too often fallen into disrepute because it was known that they had been unaltered for years, which thus gave rise to grave doubts regarding their authenticity.

All forms of specifications should be completely reprinted when amended, and old copies should be withdrawn and destroyed. Material and components standards, indexes, etc., should be maintained by the issue of frequent amendment lists, whose contents should be inserted into the appropriate volumes by the individual holders; alternatively, individual sheets should be reprinted. When these amendments have reached sufficient proportions after a period of years, the volume should be reprinted and the old one withdrawn.

It is always a contentious point as to who should carry out the physical operation of inserting amendments, and it has been frequently stated that this should be done by the standards engineering department. In the opinion of the authors this is quite impractical and has been the cause of many failures in the past. Bearing in mind that the circulation of each volume probably runs into several hundreds, a very large clerical staff would have to spend its entire time on this task alone. Even if this uneconomic policy were accepted, each volume would probably spend more time away from its rightful owner than in his possession. Standards are provided for the convenience and benefit of the recipients. It does not seem too much to ask that they should carry out the maintenance work on their own volumes. Furthermore, it would ensure that the revised sheets are read.

APPLICATION OF SIMPLIFICATION TO STANDARDS

Both the 'Lemon' Report and the Anglo-American Productivity Council's Report draw a distinction between standardization and simplification. This may be correct to some extent for end-products, but is hardly applicable to components and materials and other aspects of an internal standardization policy.

To be sound, any such policy should always have as its aim the reduction of variety of standards. Less, not more, standards should be the constant objective. This reduction in variety is fulfilling to the letter the principle of simplification, which thus becomes the automatic by-product of a properly implemented standardization policy. Desirable as reduction in variety may be, however, care must be exercised that it is not carried to excess. Merely because 40% of the items of a catalogue show only a 5% demand, it does not follow that all can be arbitrarily cancelled. Each case should be examined on its merits, and those which are found to be necessary should be retained, although not included in the preferred range.

COMPARATIVE AMERICAN PRACTICE

It is significant that all large manufacturing companies in the electrical engineering industry of the United States have standards engineering departments, the majority of which have been established for a considerable number of years. In general, these have rather more mandatory powers than are outlined in this article and frequently are solely responsible for establishing some of the material and engineering standards. To achieve this they are provided with adequate laboratories and appropriate staff, and they carry

out a certain amount of original development work.

Undoubtedly American engineers are more "standards minded" than are their opposite numbers in Britain, and as a consequence a far greater number of internal specifications and standards are prepared and actively used. The general attitude of the American engineer is that if a standard is practical and shows no financial disadvantage he will willingly use it. One consequence of this is that standards are produced in large numbers and sometimes with an insufficiently critical regard of other existing standards.

In a very large plant visited by one of the authors, the standards section and material section were separated, although working in close collaboration, but in the majority of plants they are combined in the one department. The impression was gained that a much more vigorous simplification policy could be pursued, in some cases, but the general quality of standards published was of a very high order.

Apart from the above observations, the general structure and method of operation of the standards engineering departments were broadly similar to those described in this article, although differing in detail.

GENERAL

Apart from specific products, much standardization has been carried out within industry on special items of equipment in universal use, such as ball and roller bearings. National standards have been laid down for these and at the present time, under the auspices of the International Standards Organization, the possible adoption of international standards is being closely investigated. However, much remains to be done in the creation of effective and useful standards for ball and roller bearings, as the present position from the point of view of the user is not entirely satisfactory. A revision of B.S.292, which has just been issued, is in effect no more than a list of sizes available from all manufacturers, and the tolerances show little or no improvement on the old standard. The result will be that users of the small sizes particularly, such as manufacturers of fractional-horse-power motors, etc., will still require to bore the bearing housing to closer limits than the ball- and roller-bearing manufacturers adopt, and to ensure proper fits the users will be obliged to continue the expediency of selective assembly. Some modification of tolerances would appear to be justified as well as the provision of more dimensional data, diametral clearances, etc., all of which are extremely important to the user. In addition, it is felt that some degree of simplification could be adopted with advantage, by indicating a preferred range or preferred sizes in one dimensional unit only (*e.g.* metric) within the standard range. Although fully aware of all the difficulties of arriving at standards mutually acceptable to users and manufacturers, the authors feel that the proposals now incorporated in the present revision of B.S.292 do not sufficiently take into account the points of view of the user. Modifications on the above lines would also probably accelerate the adoption of international standards.

Also screw threads, at present different in this country, Europe and the North American continent, have come under international review, and provisional standards known as the "Unified Thread" from ¼ in. upwards have been agreed between this country, America and Canada. Much remains to be done on this most involved of subjects, but this new thread is already being specified in certain special applications where interchangeability is of paramount importance, such as equipment for the defence services, and doubtless future years will see it gradually replacing the present Whitworth and metric type threads.

Many more cases of successful standardization or degree of standardization or simplification might be instanced. In this connection, the authors strongly recommend the most careful study of the Report of the Anglo-American Council on Productivity on "Simplification in Industry," and the Report of the 'Lemon' Committee, appointed by the Minister of Supply, on "Standardization of Engineering Products." Both these reports deal with the whole subject of standardization, including simplification and specialization, in a most comprehensive but extremely interesting manner. In particular, a large number of examples are given of the successful application of standardization in its three forms, and in Appendix III of the 'Lemon' Committee's Report is given also a well-balanced

analysis of the complexity of the issues involved, including answers to the many criticisms of standardization.

The Committee expresses itself as being strongly of the opinion that the criticisms will be groundless: firstly, if standardization and simplification are properly regarded as the current crystallization of the best known practice, and are subject to periodic review and to modification whenever this is appropriate; secondly, if the preparation or revision of national standards continues to be subject to the agreement of producer and user; and thirdly, if standardization on the national scale is applied by common consent.

CO-OPERATION BETWEEN MANUFACTURERS

In conclusion, the authors strongly advocate a greater degree of co-operation between manufacturers in the electrical industry in the preparation and implementation of standards, and a greater interchange of information on common manufacturing problems. There can be little doubt that successful standardization leads to a sounder manufacturing economy, and the wider the field that standards cover the greater will be their success. The success and prosperity of the industry as a whole is a measure of the success of each individual member.

Certainly, it is true that in America, where the spirit of independent competitive enterprise is epitomized, there is a far greater exchange of information on mutual problems than there is in Britain. The Americans take the view that it stimulates competition and keeps individual employees on their toes to maintain a lead on competitors. Such an interchange of ideas should benefit all and penalize only those who are content to rest on their laurels.

Just as successful standardization within an individual organization is dependent on co-operation between all departments, so an active comprehensive and realistic policy for the industry as a whole is dependent on the willingness of each member to share experience and co-ordinate results.

Large 220 kV Transformers for Finland

By R. M. CHARLEY, M.C., B.Sc., M.I.E.E., Mem.A.I.E.E.

IT WAS GRATIFYING to be of some service to Finland if only through the supply of transformers. Ravaged by war from two directions, a large part of her electric generating capacity in territory taken over by her enemies, her industry badly crippled, and faced with heavy demands for reparations, Finland set herself with determination to the task of reconstruction, and after five years of effort she has achieved considerable success.

One of the primary needs was to develop as rapidly as possible the hydro-electric resources of the country, and a large generating station was built at Pyhäkoski on the Oulu river by the Imatran Voima O/Y. The output of this station is stepped up to 110 kV through generator-transformers, two of which are 'English Electric' units, and thence to 220 kV by transformers also of British manufacture. The transmission pressure of 220 kV was adopted for the first time in Finland and the length of transmission for the first stage is about 300 miles.

The 220/110 kV transformers described in this article are located at Petäjävesi (Figs. 1, 2 and 3), where the new 220 kV transmission feeds into an existing 110 kV network which serves the City of Helsinki and industry in the surrounding country. The 220 kV system will be extended to interconnect with the large water power resources located in the north of the country.

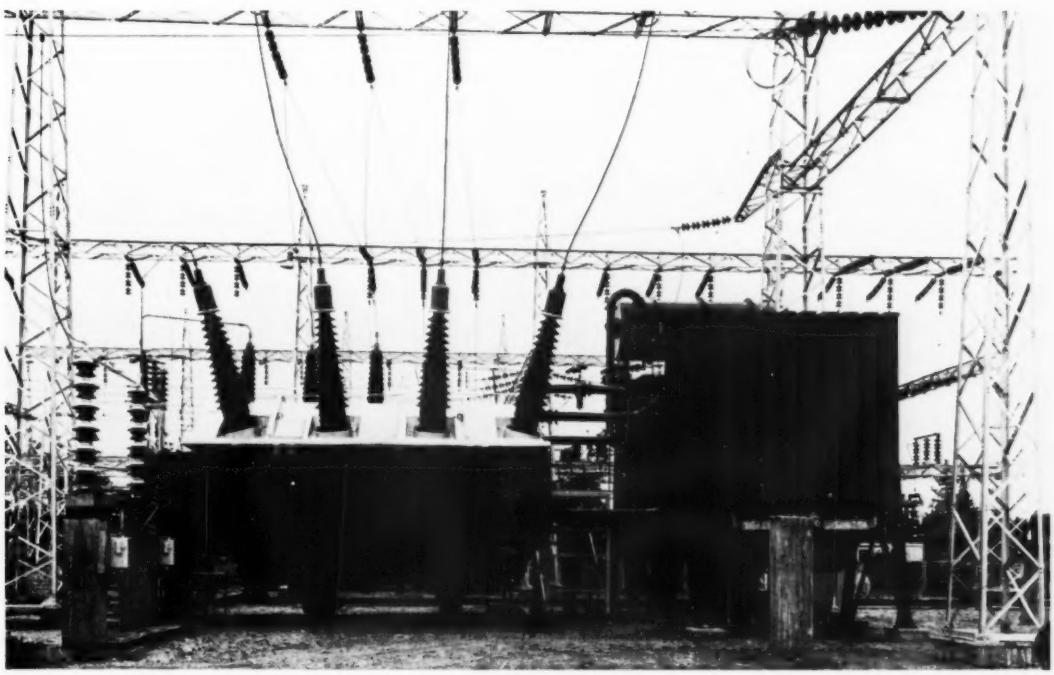


Fig. 1. One of the 64 MVA transformers as seen from the 220 kV side during erection at Petäjävesi

Main Features

The transformers are three-phase units with a nominal capacity of 64,000 kVA each. They are unique in several respects and represent a remarkable advance in the design and building of transformers, one striking feature being their great total weight, which is 240 tons each, including oil.

The main windings step-down the transmission pressure (nominally 220 kV) from 225 kV to 112.5 kV, these windings being star-connected for operation on systems with arc-suppression coil protection. This necessitates the windings being fully insulated, and unusually high insulation tests were demanded by the purchaser. On the 225 kV windings the one minute test, at 50 cycles from a separate source, was 530 kV, and on the 112.5 kV windings the test was 275 kV. The former value

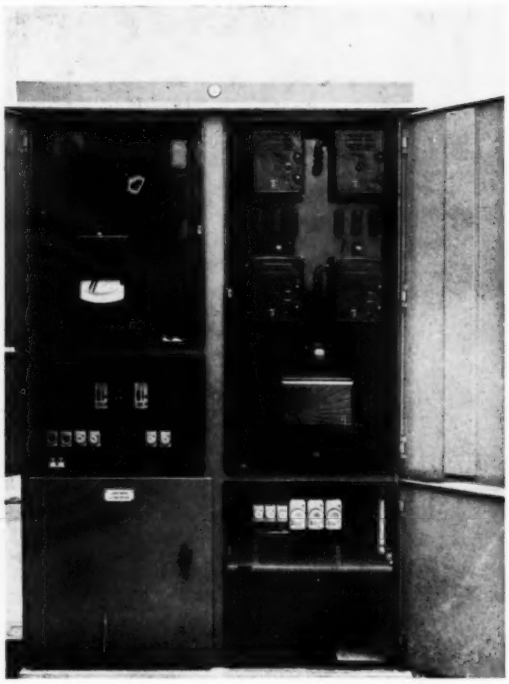
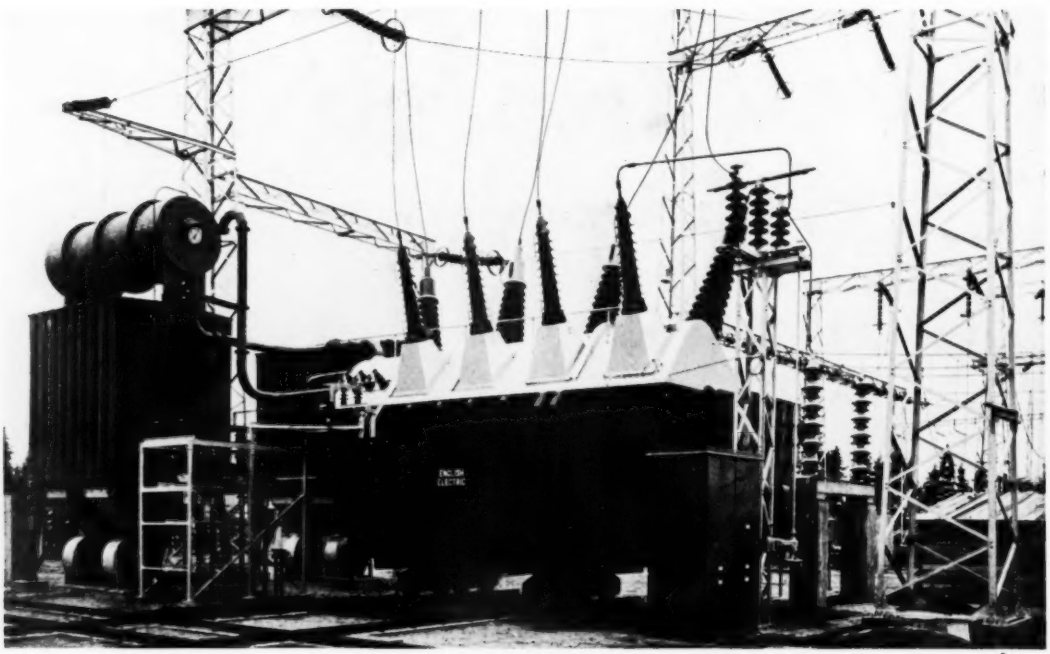


Fig. 2 (*below*). *Another view, from the* 110 *kV side, of the* 64 *MVA transformer shown in Fig.* 1.

Fig. 3 (*right*). *Local control cubicle for transformer auxiliaries, as seen in the foreground of Fig 2.*



of 530 kV is believed to be the highest test ever applied to a transformer in Great Britain at 50 cycles for one minute. The impulse level for which the windings were designed was 1,200 kV for the 225 kV winding and 650 kV for the 112.5 kV winding.

In order to provide voltage regulation on the secondary network, the 112.5 kV winding is provided with on-load tap-changing equipment for a range of plus and minus fifteen per cent in twelve steps. Considering that this winding is fully insulated and that the tap-changing gear was subjected to the insulation test of 275 kV for one minute, this represents an outstanding achievement in the design of on-load tap-changing gear.

Each transformer is provided with a delta-connected tertiary winding having a capacity of 32,000 kVA at 10.5 kV, for supplying power to a synchronous condenser.

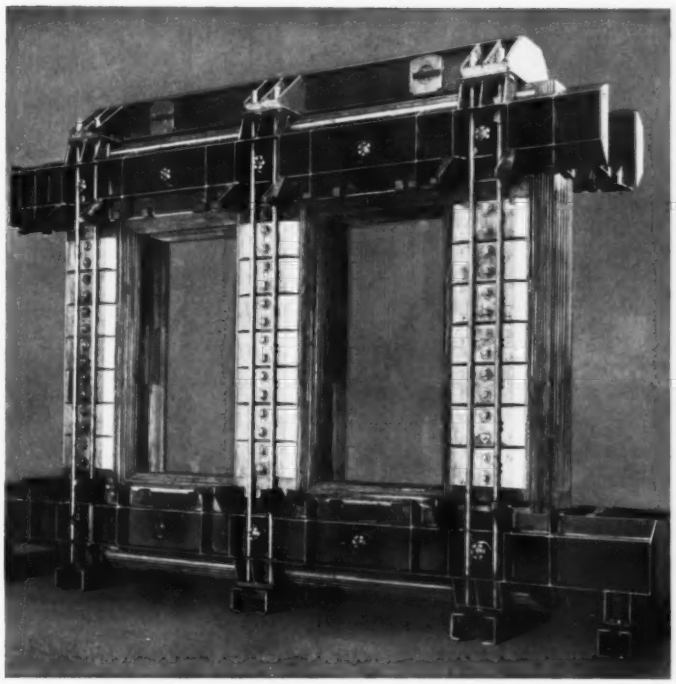


Fig. 4. The core, of standard 3-limb construction

The transformers are of the ON/OB type and are so designed that under the ON rating conditions their capacity is 32,000 kVA. The iron loss is 170 kW and the total loss when all windings are fully loaded is 575 kW.

The large size of these transformers and the very high voltage tests applied to them demanded special consideration of several aspects, but the basic features of design followed well-known 'English Electric' practice which has been fully justified by service experience of a large number of big high-voltage transformers in many parts of the world.

Core

Fig. 4 shows the core which is of the standard three-limb construction. The limbs are clamped with a single row of bolts, which has the advantage that in the event of failure of the insulation on these bolts, no serious effects can result. The laminations of the yokes as well as the limbs are arranged in a series of steps, so that for unit width of core the cross-sectional areas of limb and yoke are proportional, thus avoiding the possibility of local heating and losses at the point where the yoke laminations meet those of the limbs. Cooling of the inner portions of the limbs is provided by means of a number of transverse slots which are punched in the laminations in such a manner that a duct through the core at right-angles to the laminations is formed in a series of steps. This design provides the most efficient cooling without detracting from the effective cross-section of the core, and the cooling is in the neighbourhood of the insulated core bolts where it is essential that the temperature of the steel is limited to a value appropriate to the insulating material on the bolts.

Every step was taken to reduce the weight to be transported in a single piece. The clamping plates on the limbs of the core, and some other details of the frame construction, were made of an alloy of aluminium. The main frames were built

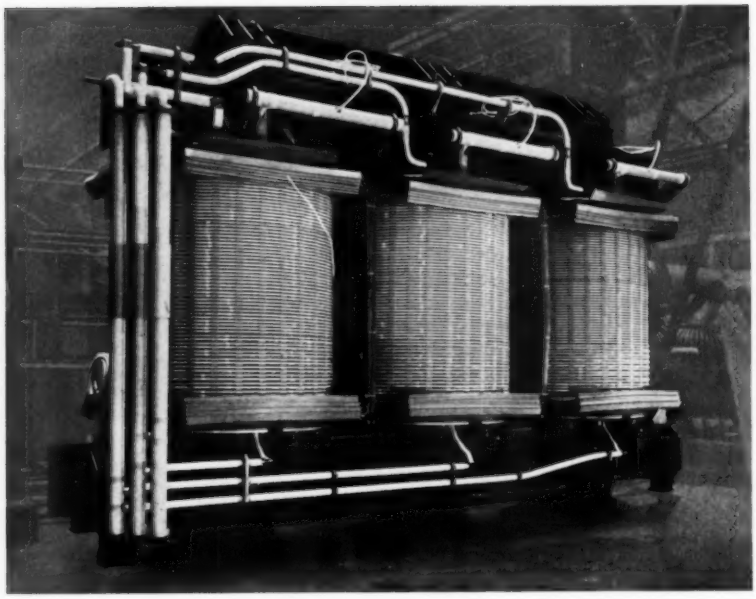


Fig. 5.
Completely assembled core and windings, showing the 112.5 kV and 10.5 kV leads

up as a fabricated structure giving the maximum strength with the minimum weight ; these frames are used to clamp the yoke laminations by means of three heavy bolts on the centre-line of each limb.

An important feature of the core construction is that between the top and bottom frames high-tensile steel bolts pass down along the face of each limb on each side, thus holding the frames together and forming a cradle for the windings. As the windings are clamped between the frames, the laminated structure of the core is relieved of all undue strains when lifting the core and windings or under short-circuit conditions. It cannot be over-emphasised that the mechanical design and construction of the core and frames of a big transformer are vital to its reliability in service.

Windings

Fig. 5 shows the completely assembled core and windings, weighing 76 tons, seen from the side where the 112.5 kV and the 10.5 kV leads are brought out. The windings are arranged in a concentric formation, the 10.5 kV winding being nearest the core limb ; outside this winding is located the tapping winding for on-load tap-changing on the 112.5 kV winding. The main portion of the 112.5 kV winding surrounds the tapping winding, and on the extreme outside is the 225 kV winding.

The 10.5 kV winding is wound as a continuous disc spiral on the foundation of a bakelised paper cylinder, axial oil ducts being formed by strips of fullerboard along the length of the cylinder on which there are dovetailed sectors of fullerboard forming radial ducts between the coil sections.

The tapping coil for the 112.5 kV winding is formed with six sections each wound as a separate disc-spiral winding spread over the whole length of the coil stack and so arranged that the tapping leads are brought out at the bottom. The main 112.5 kV winding comprises a column of disc coils wound in a special manner as described below for the 225 kV winding.

The 225 kV winding comprises a column of disc coils wound in the interleaved manner in accordance with 'English Electric' Patent No. 587,997. The special feature of this design relates to impulse strength which is considerably improved by the greatly increased series capacitance between turns and sections in relation to the capacitance to earth, compared with a conventional winding. This characteristic is obtained by arranging the turns so

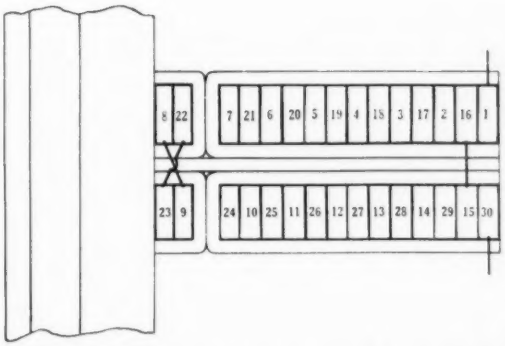


Fig. 6. Diagrammatic cross-section of one double-section disc coil for 225 kV winding, showing patented interleaved arrangement

that, electrically, a turn is located between two turns further along the winding, as shown diagrammatically in Fig. 6. This special construction, which is used throughout the length of the 225 kV and 112.5 kV windings, ensures the highest possible impulse strength with the most economical utilisation of insulating material. Although diagrammatically the process of forming the winding appears to be difficult, it is actually quite simple and is similar to the very common method of winding pairs of double-section disc coils, except that two wires are wound together with the appropriate transposition between them on the inside.

An interesting feature is that the solid insulation technique is employed. Round the outside of the 112.5 kV winding is wrapped a cylinder of the appropriate thickness, formed of thin fullerboard, and the 225 kV winding is formed tightly on this cylinder. A similar cylinder is also provided between the tapping coil and the main 112.5 kV winding. In order to provide solid insulation between the 225 kV winding and the 112.5 kV winding and the yoke, the ends of the main insulating cylinder are " petalled " and folded over at right-angles to the axis of the cylinder, thus forming a series of solid angle-rings which are interleaved with horizontal washers and vertical barriers between the outer windings of adjacent phases. This method of construction ensures the greatest possible factor of safety in an economic manner.

Tap-changing Gear

The tapping leads are brought from the three phases to one end of the tank where the on-load tap-changing gear is mounted. These are shown

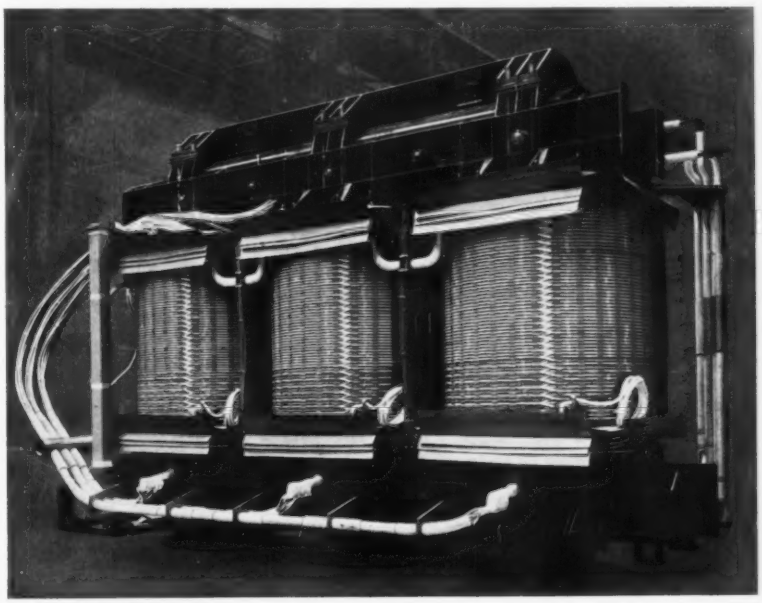


Fig. 7.

Core and windings, showing the 112.5 kV tapping leads, the 225 kV leads (bottom) and neutral connections (top)

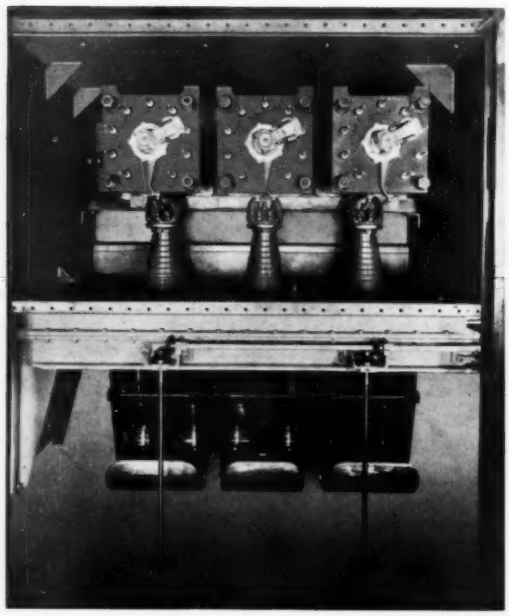


Fig. 8. On-load tap-changing gear, with selector switches in upper chamber and divertor switches below

in Fig. 7, which also shows the 225 kV leads coming from the bottom of the windings, and the neutral connections at the top. As previously stated, the whole of the 112.5 kV winding and on-load tap-changing gear was tested at 275 kV 50 cycles for one minute.

The tap-changing scheme incorporates the mid-point auto-transformer principle which has been successfully employed on ' English Electric ' transformers totalling more than twelve million kVA. It has the great benefit that it does not demand high-speed operation which is an essential requirement of tap-changing gear employing resistors, and in emergency it may remain in a mid-position without detriment.

Details of the equipment are shown in Fig. 8. The selector switches are located in the upper chamber which is open to the main tank, and the divertor switches are located in the lower chamber which is arranged so that it can easily be lowered for maintenance purposes without draining off any oil. In order to economize cost and space, the four leads for each phase pass down to the divertor-switch chamber inside a single bushing. Motor-operating gear is provided for remote operation from the control room.

Bushings and Cooling

There are four condenser bushings for both the 225 kV and 112.5 kV windings, and porcelain bushings are used for the 10.5 kV winding. All bushings are mounted in the cover, which is

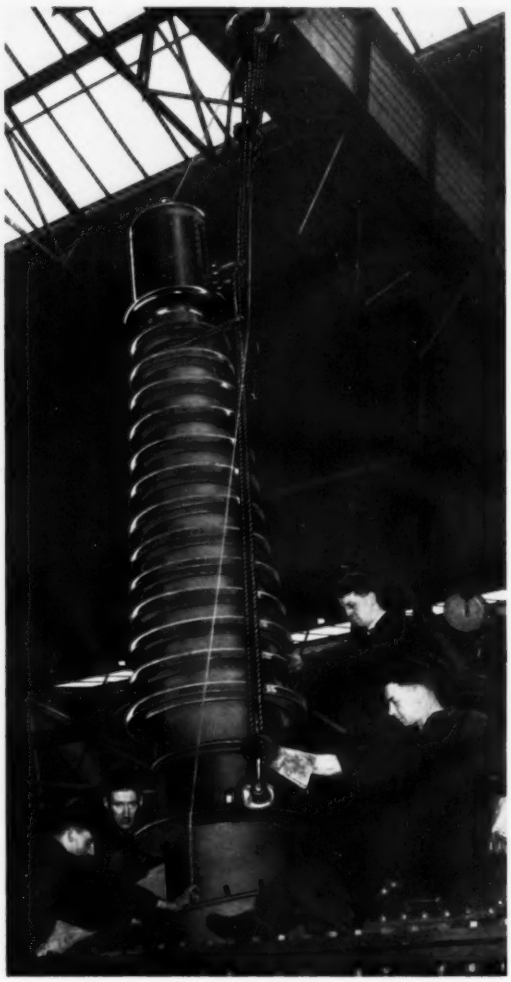


Fig. 9. A 225 kV terminal bushing being mounted in the cover

Fig. 10. *Core and windings leaving Stafford Works in their own tank with special shipping cover*

specially shaped. Fig. 9 shows one of the 225 kV bushings being mounted.

Two separate coolers are located at one end of the main tank : radiating surface is provided by detachable radiators formed with elliptical tubes welded into headers at top and bottom, these headers being bolted on to main headers through simple valves which enable a radiator to be removed without draining oil from more than the one radiator. Underneath each bank of radiators are two fans, the air from which is distributed amongst the tubes of the radiators through a system of diffusing ducts. The fan motors are brought into service automatically by a thermostat device controlled by the temperature of the oil. When the fans are not running, the transformer is capable of carrying 32,000 kVA on the main windings and 16,000 kVA on the tertiary winding, or such other load proportions for which the losses do not exceed the appropriate values.

Every precaution was taken to eliminate places in which gas could be trapped, so that any gas bubbles developed under fault conditions will collect in the Buchholz protective device.

Dimensions and Transport

The transformer tank is 32 ft long over the on-load tap-changing gear, 13 ft wide, and 25 ft high over the bushings. Including the coolers, the overall dimensions of the transformer are 54 ft long, 32 ft wide and 28 ft high.

The transport of such a large transformer was a serious problem, especially as the maximum load allowable on the railways of Finland was 90 tons and it is very desirable practice to ship a transformer, particularly a large high-voltage unit, with the core and windings in their own tank. The construction was arranged to conform to the available railway truck, and some of the stiffeners on the tank walls were made removable ; their removal was not detrimental when the tank was devoid of oil, and much advantage was gained in weight and dimensions. In Fig. 10 the core and windings, in

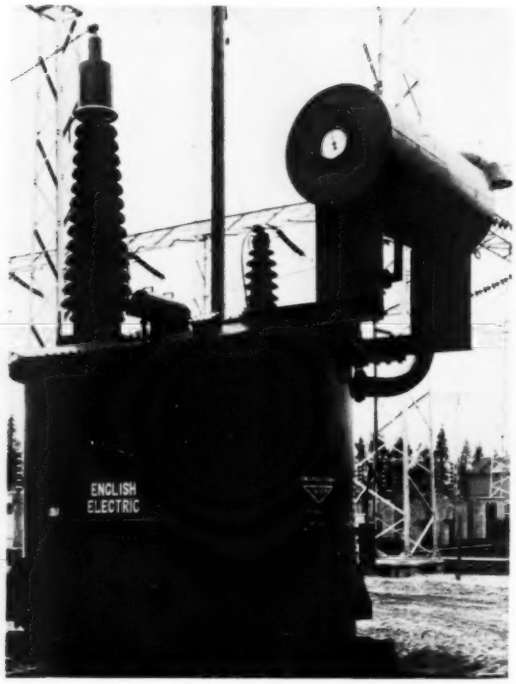


Fig. 11. *A 225 kV arc suppression coil at Petäjävesi, Finland*

their own tank with a special shipment cover, are leaving the Company's Stafford Works.

This transport achievement has considerable value compared with shipping the core and windings separately from the main tank, particularly in relation to assembly and drying out on site, which are reduced to the minimum.

Arc Suppression Coils

As already mentioned, the 220 kV and 110 kV transmission systems in Finland are equipped with arc-suppression coil protection, and three 225 kV coils were supplied by this Company. The 225 kV coils were designed with a half-hour rating for a maximum fault current of 180 amperes, and have a series of tappings for tuning down to 120 amperes. The tappings are connected to a tapping-switch for operation only when the coil is disconnected from the line, and the tapping switch is provided with motor-operating gear for remote selection of tappings from the control room. The total weight of each coil is 51 tons and the overall height is 24 ft. Fig. 11 shows a complete coil on site.

Conclusion

The construction of the transformers described in this article represents a landmark in British transformer practice, especially considering the very high insulation tests demanded. These tests, incidentally, presented a much greater design problem than the 275 kV transformers now being built for the British Electricity Authority for the new 275 kV system which will reinforce the existing 132 kV Grid, both these systems being operated with the neutrals solidly grounded.

High Frequency Alternators

By N. S. SIM, M.C., B.Sc., A.R.T.C., Machine Design Department.

Influence of Frequency on Type and Design

THE ILLUSTRATIONS in this article of some ' English Electric ' high-frequency alternators show changes in type and design necessitated by the increasing limitation of available space in the active annular belts of rotor and stator, adjacent to the air gap, as the number of frequency defining units is increased. The frequency defining unit is the pole pair of the ordinary salient pole alternator, and the analogous tooth-plus-slot unit of the rotor of the inductor alternator.

Fig. 1 is a somewhat extreme example of a 3-phase heteropolar salient pole alternator having a rating of 150 kVA 400 cycles per second at 1,500 r.p.m. Its pole pitch is about $2\frac{1}{2}$ in. as measured on the bore. The endeavour to make full use of the available space for poles and coils on the rotor of this 32-pole alternator will be apparent.

All the other illustrations are of single-phase alternators.

The first departure from conventional salient pole design, to give improved efficiency in the use of available rotor active space, is the adoption of a slotted rotor on which every tooth is a pole and the number of exciting coils is halved by winding alternate teeth only, with coils of similar polarity, leaving the intermediate teeth to be oppositely magnetised by " consequent pole " effect.

This type of rotor is illustrated in Figs. 2 and 3, showing the 88-pole rotor of a 150 kW 2,200 cycles per second 3,000 r.p.m. alternator, and in the nearer machine of the 1,500 r.p.m. motor-generator set in Fig. 4, which is an 80-pole 1,000 cycles per second 400 kW alternator.

In the examples given so far, the exciting systems have comprised coils wound on the rotor, each coil spanning roughly one pole pitch. As the frequency is further increased and the pole pitch decreased, this arrangement ceases to be a practicable proposition and we pass into the sphere of usefulness of the inductor alternator. In this the exciting coils are transferred to the stator, so removing the necessity for sliprings and their brushgear, and the number of exciting coils is no longer anchored to the frequency.

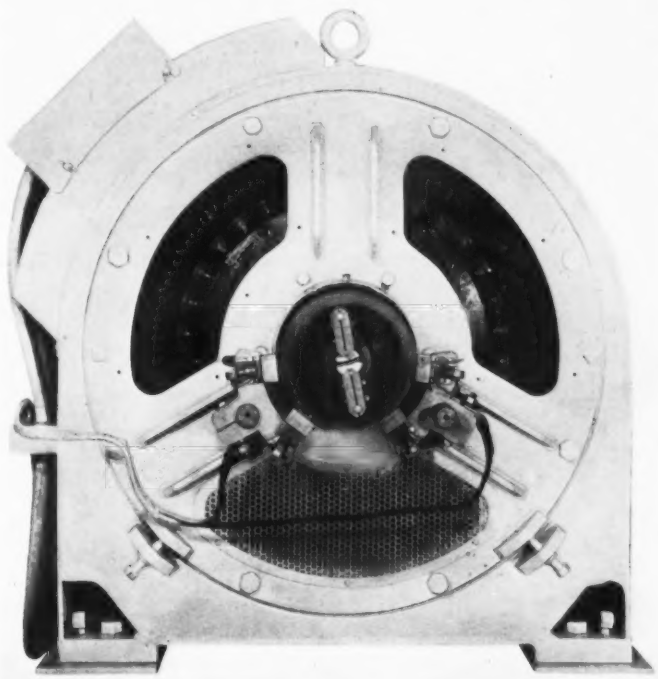


Fig. 1. *A 3-phase heteropolar salient pole alternator,* 150 *kVA* 400 *cycles per second at* 1,500 *r.p.m.*

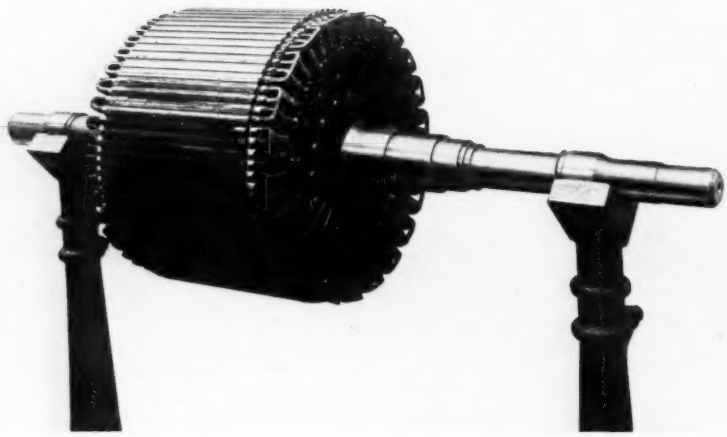


Fig. 2. The 88-pole rotor of a single-phase 150 kW 2.2 kc. 3,000 r.p.m. alternator

The Inductor Alternator

The inductor alternator utilises quantitative variation of uni-directional magnetic flux, instead of the successive north-south reversal of flux of the normal salient pole alternator. Its rotor is of plain unwound toothed construction, and may be looked upon as being a mechanical device for causing quantitative variation of magnetic flux in stator teeth around which the high-frequency coils are wound. Alternating voltage is generated in these coils in much the same way as in transformer coils. In the transformer core the magnetic flux reverses cyclically in time. In the stator teeth of the inductor alternator the flux is uni-directional but is caused, by the rotation of the rotor, to vary in quantity cyclically in time. Rotor tooth opposite stator tooth gives maximum flux in the stator tooth; rotor slot opposite stator tooth gives minimum flux in the stator tooth.

Two types of magnetic field system may be used, namely homopolar and heteropolar.

The homopolar arrangement is illustrated diagrammatically in Fig. 5 and in the nearer machine of the motor-generator set in Fig. 6, which is a 150 kW 2,000 cycles per second 80-pole 1,500 r.p.m. alternator. The reduction in the power required for excitation through the use of a single, although sub-divided, exciting coil, is reflected in the smallness of the exciter in this set.

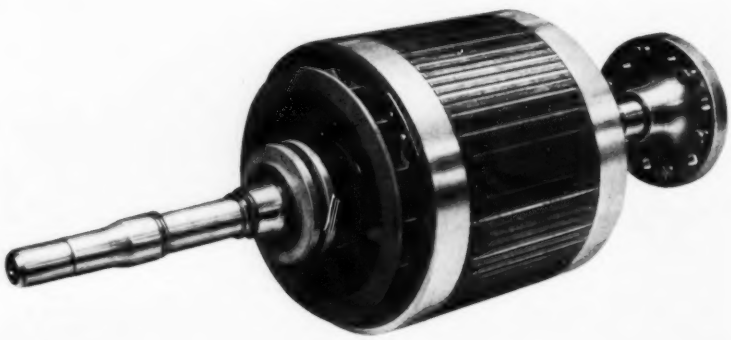


Fig. 3. The rotor shown in Fig. 2, completed

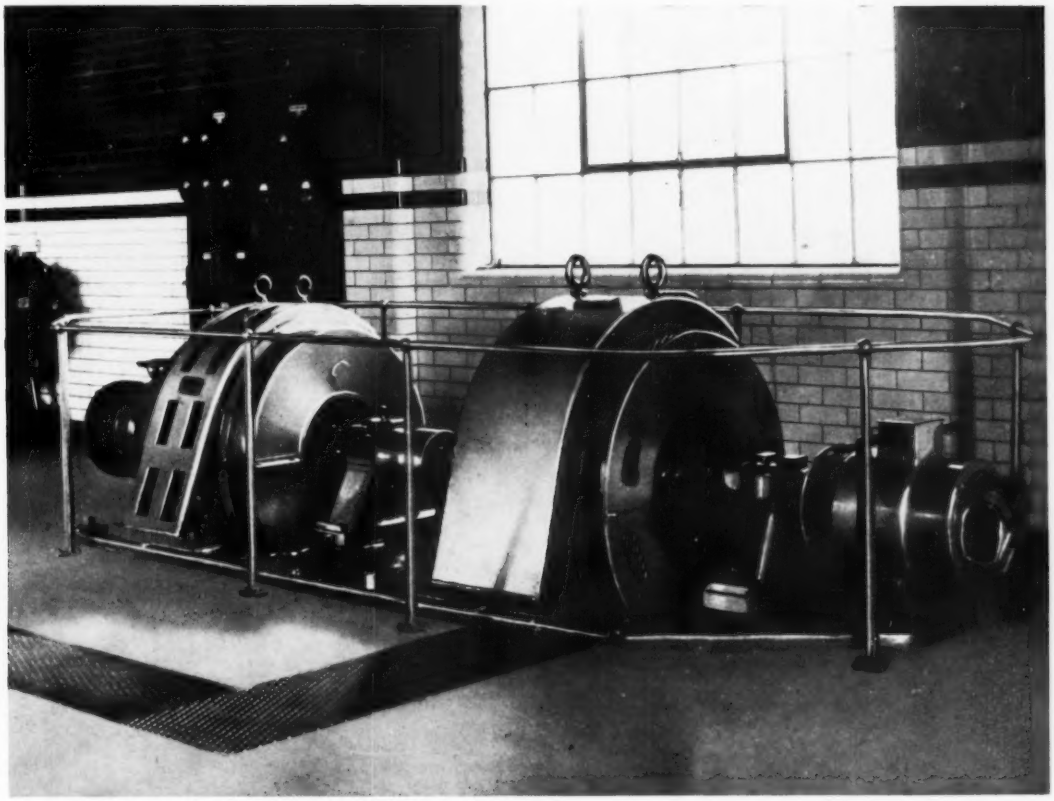


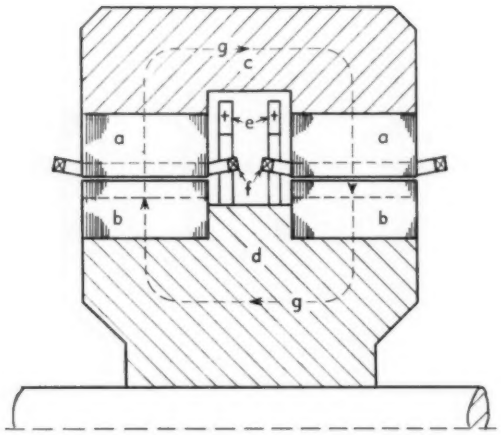
Fig. 4. *Motor-generator set with* 80-*pole* 400 *kW* 1 *kc.* 1,500 *r.p.m.* "*consequent pole*" *alternator in foreground*

The heteropolar arrangement is illustrated in Figs. 7 to 12 inclusive. Figs. 7 and 8 show the stator and rotor of a 160 kVA 2,250 cycles per second 3,000 r.p.m. alternator having six exciting coils but rotor slotting equivalent to 90 poles, the complete alternator, with terminal cover removed, being shown in Fig. 9. Figs. 10 and 11 show the stator and rotor of a 30 kW 10,000 cycles per second 3,000 r.p.m. alternator having six exciting coils but rotor slotting equivalent to 420 poles; a portion of the unwound core of the stator is shown in Fig. 12.

The heteropolar arrangement has the advantages that it leads to a construction which is more in line with that of normal A.C. machines, and the number of main exciting coils may be chosen so as to give a main pole flux consistent with the use of existing coreplate dies. It may be noted here that with the heteropolar arrangement the shaft is not magnetised as is the case in the homopolar arrangement (Fig. 5) and in the consequent pole design (Fig. 2).

The rotor of the heteropolar alternator is subject to additional iron losses corresponding to reversal of magnetic flux in accordance with the number of main exciting coils and the speed; for example, in the machines previously mentioned, iron loss corresponding to flux reversal at 150 cycles per second, *i.e.*, as for a 6-pole alternator running at 3,000 r.p.m.

For stator slotting in inductor alternators two main types emerge. First, an arrangement where the number of stator slots is twice the number of



a. Laminated stator core.
b. Laminated rotor core.
c. & d. Solid cores.
e. Sectionalised exciting coil concentric with shaft.
f. High-frequency coils.
g. Main flux path.

Fig. 5. Magnetic field arrangement of homopolar alternator

rotor teeth. This is illustrated in Figs. 13 and 7. With further increase in frequency, when the pitch of the high-frequency coils and the available space for these again become impracticably small, an arrangement may be adopted where " major " stator teeth on which the high-frequency coils are wound have, on their bore surfaces, a number of " minor " teeth whose pitch corresponds to the pitch of the rotor teeth. This type of slotting is illustrated in Figs. 14, 10 and 12.

It will be seen that for both these types of slotting a movement of the rotor through half a rotor tooth pitch changes the flux quantity in the tooth on which the high-frequency coils are wound from maximum quantity to minimum quantity; this is equivalent to a change from full north pole flux to full south pole flux through a stator coil of the normal heteropolar alternator, that is, equivalent to half a period of voltage variation.

The variation, in time, of the flux quantity in the stator tooth will be roughly as indicated by the full line on the diagram in Fig. 15. For reasonably normal proportions of teeth and slots in the stator and rotor, this variation of the flux quantity, in

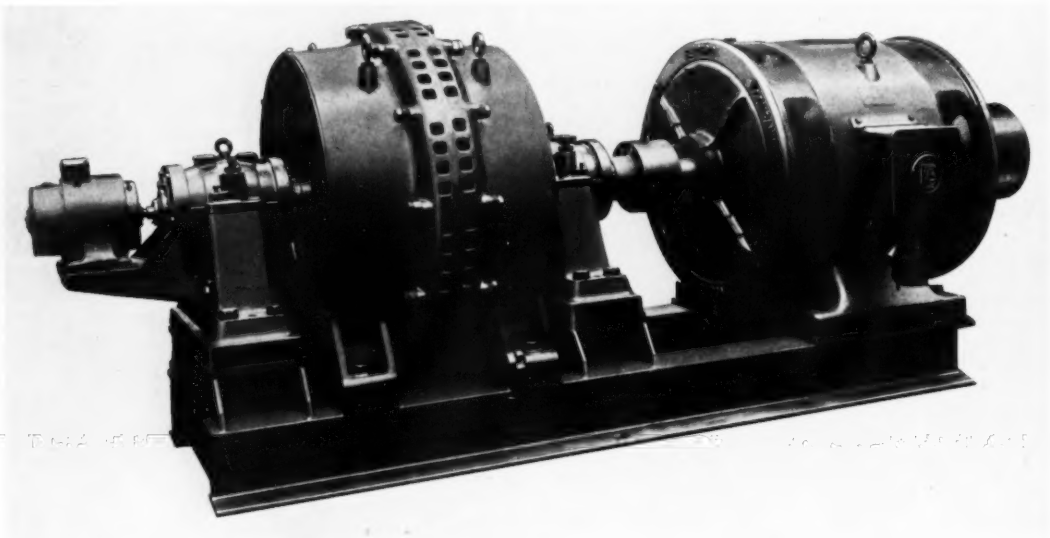


Fig. 6. Motor-generator set with 80-pole 150 kW 1,000 volts 2 kc. 1,500 r.p.m. homopolar alternator on left

time, will not depart widely from sine wave variation, in time. This will be reflected in the voltage wave being approximately of sine wave form. Fig. 16 shows the open circuit voltage wave of the small 10 kc. alternator, of which the stator and rotor are illustrated in Figs. 10 and 11.

The generated high-frequency voltage will be proportional to the range of flux quantity in a stator tooth, that is, to maximum tooth flux minus minimum tooth flux, which in Fig. 15 is represented by an ordinate of A minus the corresponding ordinate of B. The quantity $\frac{A-B}{2}$ in the inductor alternator is equivalent to the flux per pole of the normal salient pole alternator. It will be noted that in order to get quantity $\frac{A-B}{2}$ we have to make provision for maximum flux A, and $\frac{A-B}{2}$ may be small in comparison with A. To this extent, then, the inductor alternator may be considered inefficient in its use of flux.

Fig. 7. Stator of a single-phase 160 kVA 1,200 volts 2.25 kc. 3,000 r.p.m. heteropolar alternator

The equivalent uniform air gap for maximum tooth flux position is considerably smaller than the equivalent uniform gap for minimum tooth flux position; hence, for any reduction in actual air gap the resultant increase in maximum flux is relatively greater than the increase in minimum flux, and the useful range of flux quantity, to which the voltage is proportional, is correspondingly increased. The desire to increase output by reduction of air gap must be tempered by the necessity to retain a gap sufficient to ensure reliable service.

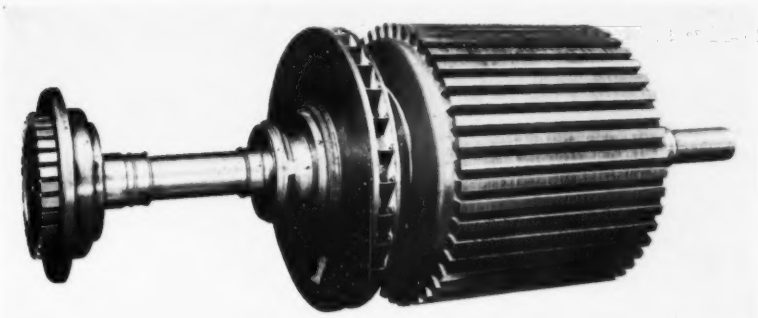


Fig. 8. Rotor for the same alternator as the stator in Fig. 7

As the rotor tooth pitch is reduced, with increasing frequency, the difference between maximum and minimum tooth flux, *i.e.*, the flux variation, diminishes rapidly. Therefore the output which can be obtained from a given machine frame size is reduced as the frequency is increased.

The facts that the inductor alternator operates on variation of uni-directional flux and not on flux reversal, and that the flux variation decreases with increase in frequency, will go far to explain why there is no evidence of imperfect penetration of flux in these alternators, and why iron loss does not attain unmanageable proportions.

In these inductor alternators it is necessary that the main flux, that is, the total flux of the homopolar type and the flux per pole of the heteropolar type, should be as nearly constant as possible. If this is not so, undesirable high-frequency voltage will be induced in the exciting coils by high-frequency variation of main flux quantity, and, in the homopolar machine, high iron loss will occur in the solid parts of the magnetic circuit through the same cause. It is therefore necessary that the overall reluctance of the air gap should not vary, in time, to any appreciable extent.

The graphs which follow all relate to the small 10 kc. alternator (Figs. 10 and 11) whose rotor tooth pitch is approximately 0.3 in., that is, an equivalent pole pitch of approximately 0.15 in. The special characteristics which the graphs illustrate are the more pronounced because of the smallness of the polar dimensions.

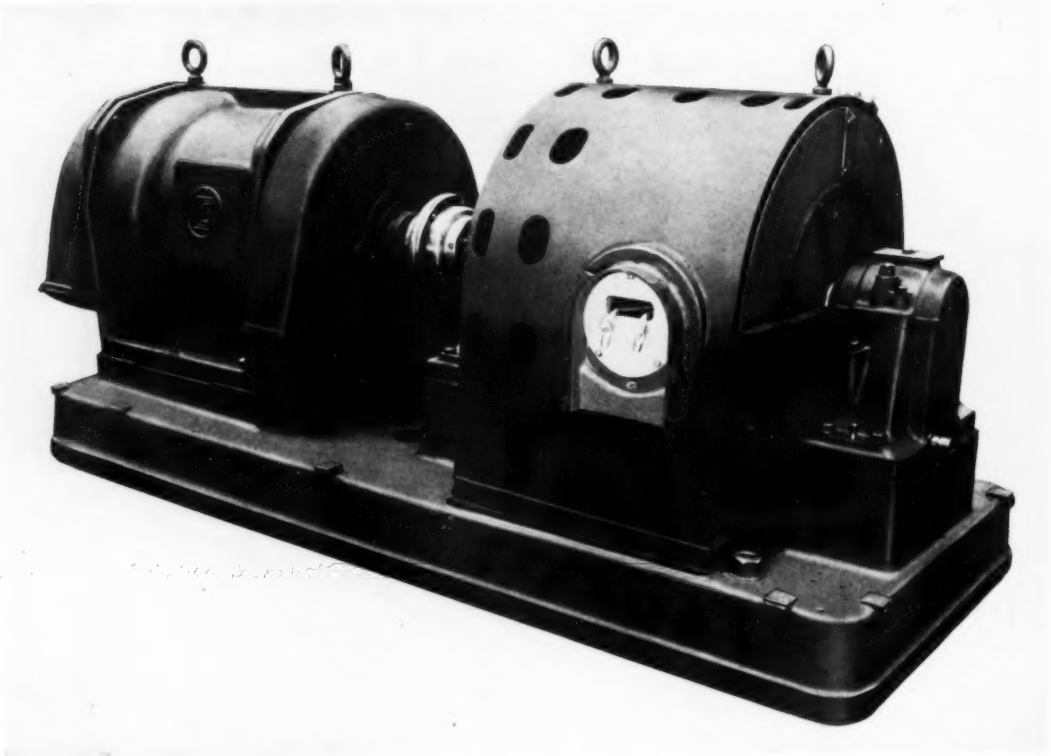


Fig. 9. The complete alternator (right) incorporating the stator and rotor shown in Figs. 7 and 8, coupled to its driving motor

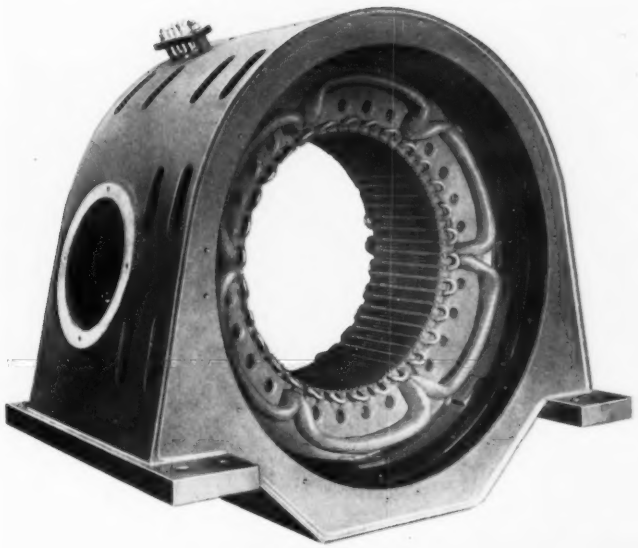


Fig. 10. *Stator of a* 30 *kW* 10 *kc.* 3,000 *r.p.m. heteropolar alternator*

Open Circuit Characteristic

An unusual characteristic of the inductor alternator is that on open circuit with increasing excitation the terminal voltage reaches a maximum value, and further increase in excitation is accompanied by continued decrease in voltage. The explanation is that the effect of magnetic saturation is greater, and becomes apparent earlier, when the stator tooth is in its maximum flux position than when in minimum flux position.

In Fig. 17 graphs "f_1" and "f_2" are measured maximum and minimum stator tooth flux quantities. The relative effects of magnetic saturation are apparent by the more rapid bending over of curve "f_1" as compared with "f_2." With increasing excitation a point is reached where the difference between maximum and minimum stator tooth fluxes ceases to increase and then decreases; the voltage of the alternator behaves accordingly. This is shown in graph "c" in which the differences of the ordinates of graphs "f_1" and "f_2" are plotted. Graph "c" is repeated in Fig. 18 but suitably scaled for comparison with the open circuit voltage curve "a." The agreement between graphs "a" and "c" is reasonably good considering that the measurement of tooth fluxes and the positioning of the rotor for this purpose were effected under ordinary commercial test conditions.

In the open circuit curve given in Fig. 18 the maximum value of voltage is fairly sharply defined and the subsequent falling away in voltage is rapid. It will be readily understood that as the tooth pitch increases, the peak of the open circuit curve flattens out and the falling away of voltage becomes slower.

Reaction or Reactance ?

In these single-phase heteropolar alternators the

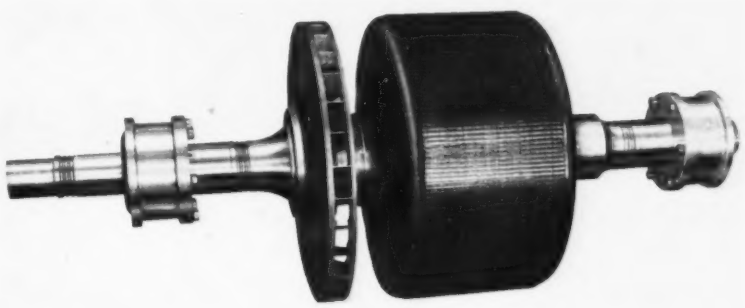


Fig. 11. *Rotor for the same alternator as the stator in Fig.* 10

relative disposition of currents in the high-frequency winding and main excitation coils are as given in Fig. 19. The same relative disposition holds good for the high-frequency winding and the exciting coil of the homopolar alternator. This system of currents in the high-frequency winding has no resultant magnetomotive force reaction on the m.m.f. of the main exciting coil. From this purely m.m.f. point of view it is correct to say that such alternators have no stator reaction. This statement, however, requires some modification when the complete action of the high-frequency winding is considered, since the inter-action between the high-frequency winding m.m.f. and the decrease of magnetic saturation in the stator tooth at maximum and minimum flux produces a result which is of a nature similar in its effect to that of a reaction. As will be seen later, this " saturation reaction " has little effect under lagging power factor conditions but may become quite appreciable with a leading power factor.

The relative position of stator and rotor teeth at the instant of maximum high-frequency current on zero lagging power factor is shown in Fig. 20, where the main exciting m.m.f. is indicated by full line arrows and the m.m.f. of the high-frequency current by dotted lines which may also be taken to indicate the leakage flux if unaffected by the main excitation m.m.f.

The total leakage flux is made up of three parts:—

(*a*) that part which encircles the core portion of the stator coils and crosses the air gap.

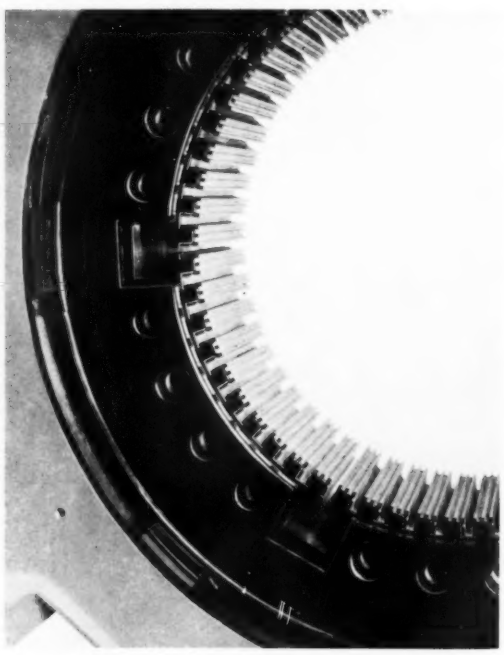


Fig. 12. *A portion of the unwound core of the stator shown in Fig.* 10

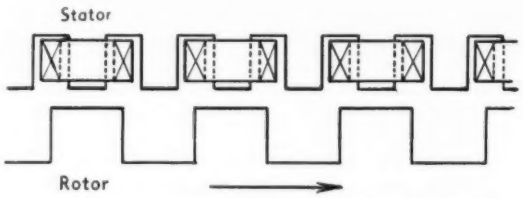


Fig. 13. *Arrangement of stator slotting for inductor alternator in which the number of stator slots is twice the number of root teeth*

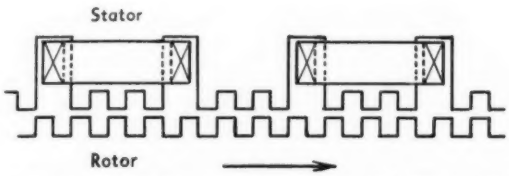


Fig. 14. *Slotting arrangement for inductor alternator with " major " and " minor " stator teeth as shown in Figs.* 10 *and* 12

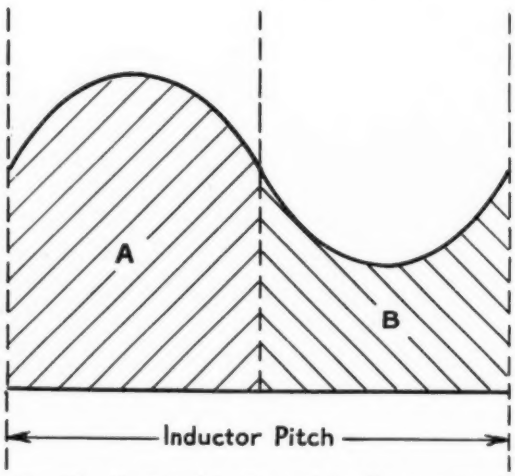


Fig. 15. *Variation, in time, of the flux quantity in a stator tooth*

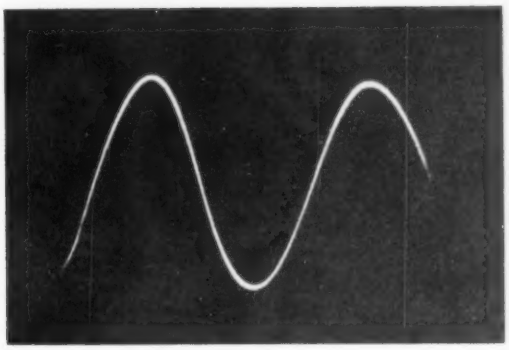
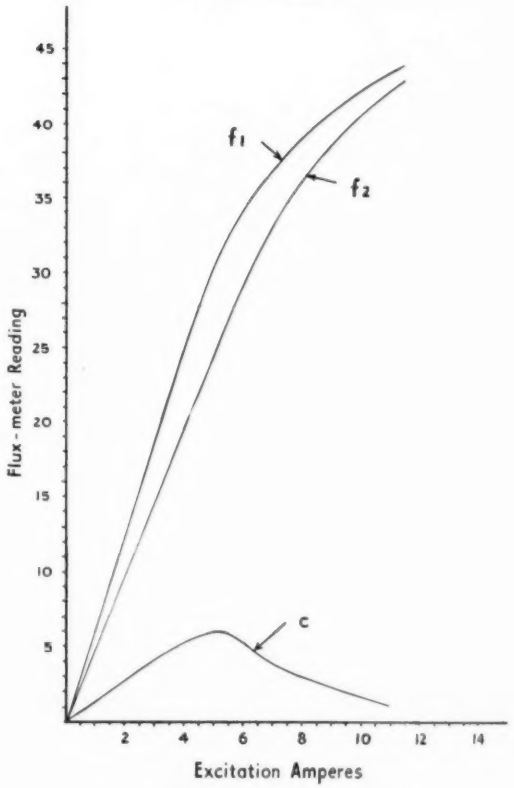
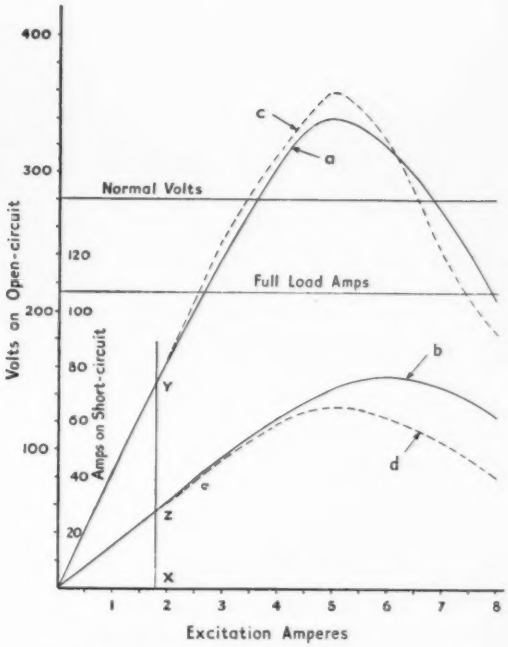


Fig. 16. *Open circuit voltage wave of the* 10 *kc alternator of which the stator and rotor are shown in Figs.* 10 *and* 11



f_1 Maximum flux in stator tooth.
f_2 Minimum flux in stator tooth.
$c = f_1 - f_2$

Fig. 17. *Maximum and minimum stator tooth flux quantities*



a. Volts on open circuit.
b. Current on short circuit.
c. Variation of difference between maximum and minimum stator tooth flux, as obtained by flux-meter test, and scaled to demonstrate degree of agreement with open-circuit characteristic (a).
d. Short-circuit current calculated from open-circuit voltage and "unsaturated" reactance of high-frequency winding.
The "unsaturated" reactance of the high-frequency winding is the ratio of volts to amperes for the straight-line parts of the O.C. and S.C. characteristics for the same excitation, e.g. $\frac{XY}{XZ}$ ohms.

Fig. 18. *Open circuit and short circuit curves for an inductor alternator*

(*b*) the portion which crosses the slot.

(*c*) the leakage flux of the overhang of the coils, which is relatively small and for the present purpose will be neglected.

It will be seen that whatever influence leakage fluxes " a " and " b " have on the maximum tooth flux they have the same quantitative effect, but in the opposite sense, on the minimum tooth flux and, if magnetic saturation were of no account, the result would be the distortion of the main flux with no effect on its magnitude. This is a reactance and not a reaction effect.

Sustained Short-circuit

On sustained short-circuit the conditions are zero lagging power factor—as in Fig. 20—and zero terminal volts. If we include the small reactance voltage of the overhang leakage flux, the high-frequency current on sustained short-circuit will reach a value at which maximum tooth flux is decreased and minimum tooth flux is increased so that their values are equal, that is, there is no flux variation, which is the condition for zero terminal voltage.

In Fig. 21, Φ_{T_1} and Φ_{T_2} are values of maximum and minimum stator tooth flux on open circuit for excitation OX. If the terminals of the alternator be short-circuited, the current in the high-frequency winding will be such as to produce a high-frequency winding leakage flux of $\frac{\Phi_{T_1}-\Phi_{T_2}}{2}$ so that the maximum tooth flux quantity is reduced to the value Φ_{T_1}', and the minimum tooth flux quantity is increased to Φ_{T_2}', that is, both equal to Φ_{T_3}, giving zero terminal voltage.

The current on sustained short-circuit at any excitation is such that the high-frequency winding reactance voltage is equal to the open circuit voltage for the same excitation, provided that magnetic saturation conditions are unaffected. The actual conditions are that maximum flux, where saturation is greatest, has been reduced, and the minimum tooth flux, which is not so much affected by saturation, has been increased, so that we would expect the alternator to behave as if magnetic saturation had somewhat less effect on short circuit than on open circuit. For example,

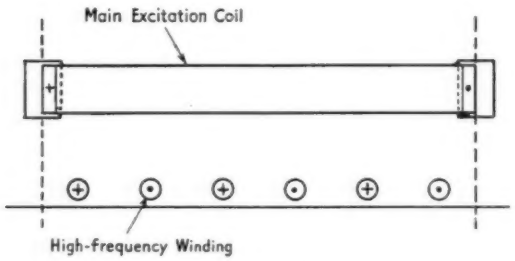


Fig. 19. Relative disposition of currents in the high-frequency winding and main excitation coils of a single-phase heteropolar alternator

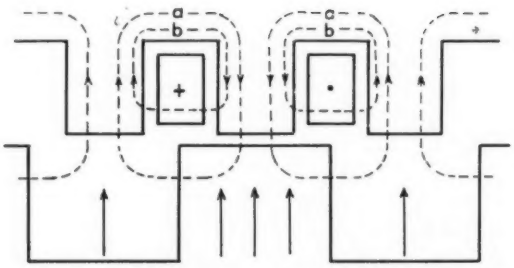


Fig. 20. Relative position of stator and rotor teeth at the instant of maximum high-frequency current on zero lagging power factor

with increasing excitation we might expect the growth in short-circuit current to persist further than the growth in open circuit voltage. From Fig. 18 it will be seen that this is so.

On Leading Power Factor

On zero leading power factor the high-frequency winding leakage flux will have the reverse effect to that previously described for zero lagging power factor, that is, the maximum tooth flux will be increased and the minimum tooth flux reduced so that the difference or flux variation will be considerably increased. Hence, if we can arrange to cause the alternator load current to be leading we should get considerably increased terminal voltage. In this case, however, the high-frequency winding is trying to increase the maximum tooth flux where the effect of saturation may already, on open circuit, be having its effect, and the quantitative leakage flux effect is the same on maximum tooth flux and on minimum tooth flux; therefore the magnetic saturation in maximum tooth flux becomes reflected in minimum tooth flux and the main flux is quantitatively reduced. Hence, at leading power factor, the effect of the interaction between the high-frequency winding and magnetic saturation is of the same type as a reaction.

The internal reactance voltage is produced by the equivalent of flux reversal, whilst the main voltage is produced by flux variation. The internal reactance voltage may reach a relatively very high value. In the 10 kc. alternator the internal reactance voltage is about 180%, that is, whilst the nominal terminal voltage is 280 volts the internal reactance voltage is 500 volts at full load current.

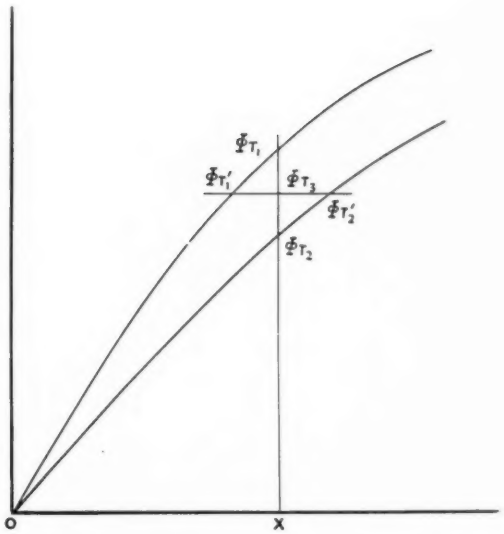


Fig. 21. *Values of maximum and minimum stator tooth flux on open circuit*

On Load

With an internal reactance of such magnitude it is necessary to keep the load current to a minimum value and to utilise the compounding effect possible with leading power factor. The load may be of low power factor. The power factor of the reactive load is brought to unity by means of static condensers in parallel with it, and use is made of static condensers in series with the alternator.

If the terminal voltage of the series condenser bank is made equal to the internal reactance voltage of the alternator, we get a tuned generating unit for the combination of alternator and series condenser bank. Perfect regulation might therefore be expected, that is, constancy of voltage across the load from no load to full load without adjustment of field current. However, it is found that this is not so, as the " magnetic saturation reaction " comes into play and some increase in excitation, depending on the degree of saturation of the stator tooth at maximum flux condition, is found to be necessary.

With the use of series condensers the voltage of the individual members of the tuned generating unit will be considerably higher than the voltage across the load which this unit supplies, and allowance must be made for this in the insulation of the high-frequency alternator. Protection must also be provided against over-current, since in the series tuned generating unit over-current would be accompanied by over-voltage across the condenser and the alternator terminals. Some measure of self protection for the alternator is given however by the increase in magnetic saturation as the load current increases.

The editor acknowledges with much appreciation the assistance of Mr. J. Bickerstaffe of the Machine Design Department in preparing this article for publication after the death of the author.

The Meter and Instrument Factory at Stafford

By A. E. BATES, M.I.E.E., Chief — Sales and Contracts, Instrument and Meter Department.

THREE MAIN FACTORS promote accuracy and efficiency in the manufacture of meters and instruments ; first, the best possible working conditions for all personnel ; second, the highest standard of equipment and maintenance in the factory with particular emphasis on cleanliness ; and third, checking at all stages not only the product but also the tools with which it is made, so that inspection becomes a matter of proving good work rather than rejecting defective components.

Fig. 1. *Pressing the main frames for meters*

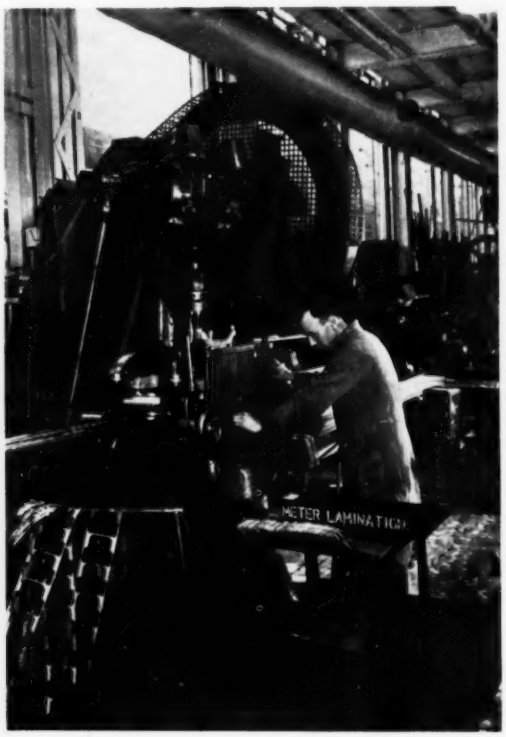


Fig. 2. *Pressing laminations for meter magnets*

The Meter and Instrument Factory at The English Electric Company's Stafford Works is a self-contained unit in a modern building, in which all the assembly work and testing is carried out. It was completed in July, 1949, and is situated in naturally clean atmosphere on the south-eastern outskirts of the town, overlooking the open country. It is equipped with air conditioning plant and has excellent natural and artificial lighting. All machining and press work is carried out in departments separate from this building so as to

Fig. 3. A small component being inspected by light projection on to the screen shown in Fig. 4

avoid the introduction of dust and grease into the assembly and testing sections.

In this article, the description of the work in the factory follows generally the logical sequence corresponding to the flow of production.

Raw materials for the manufacture of the meters and instruments are received at a central store adjacent to the machine shop, where they are inspected for compliance with order specifications. From there the materials pass either to the press shop or to the automatic machine shop for the first-stage production of components.

The press shop, two views of which are shown in Figs. 1 and 2, produces meter frames involving a series of about ten press operations, laminations for the electro-magnets, and all the other press items which go to make up the final assemblies. Skilled supervision ensures the correct setting and maintenance of all press tools.

All gear cutting for register parts is carried out in the machine shop, where particular importance is attached to gauging and inspection. One of the inspection devices is a shadow projector with a magnification of 200, used principally for proving the accuracy of gear cutting by direct comparison with master tooth forms. A component under inspection in this device, and its projected shadow, are shown in Figs. 3 and 4. By such means a continuous check is maintained on the production accuracy of vital components.

In a section adjacent to the machine shop the electro-magnets for meters are built up to a sub-assembly stage, as seen in Fig. 5. Packs of laminations, produced in the separate press shop, are weighed and assembled with the potential coil. Following this the various components such as tie-bars, overload shunt and quadrature loop are fitted prior to applying the series coil insulation and the series windings. After completion the electro-magnets are processed to ensure immunity from breakdown under high humidity conditions of service. All ferrous components including main frames and magnets are spray painted after phosphate treatment. The main frames are also assembled in this section with their light-load adjusters and power-factor adjuster units.

Fig. 4. Profile of small component in Fig. 3. projected on to screen for inspection

Fig. 5. Assembling electro-magnets for meters

Fig. 6. Finishing small components on watch lathes

Fig. 7. "Shadowgraphs" which show on screens magnified profiles of work in watch lathes

Fig. 8 (below). Microscopic examination of small components after watch-lathe operations

Complete sub-assembles of both electro-magnets and main frames then pass to the main-assembly concentration stores, while brake magnets, not yet magnetised, pass to the sub-assembly sections described later.

Finished components from the machine shops, after de-greasing and plating processes, go either to appropriate stores or to the watch-lathe section for further delicate machining operations. The watch-lathe section (Fig. 6) is located on the top floor of the new building and here such work as staking tooth wheels, jewel mounting, pivot forming and marking rotor discs takes place. Optical devices are employed for certain of the operations to ensure precision in production. Fig. 7 shows "shadowgraphs" being used for small components, the profiles of which are shown as magnified images on shrouded screens enabling the operators to compare their work as it progresses with standard profiles inscribed on the screens.

Upon completion of watch-lathe operations, microscopic examination of all finished components is carried out by a section of the Inspection Department (Fig. 8) to ensure the high standard of finish

Fig. 9. *General view of meter assembly floor, with main assembly lines for single-phase meters in foreground*

Fig. 10. *Sub-assembly of meter registers*

Fig. 11. *Sub-assembly of brake magnets*

essential for the satisfactory performance of meters and instruments.

On the same floor of the building is the Standardizing Laboratory for maintaining the accuracy level of sub-standards, with which is also combined the proving station for all new developments. Adjacent to this is the Model Room where new developments are produced as models for testing and proving, and also the Drawing Office and Engineering Department. Polyphase meters, and instruments of the moving iron and moving coil switchboard and portable types, are also assembled and tested on the top floor.

The main assembly and testing of single-phase credit meters take place on the next floor of the building, which is devoted entirely to this work (Fig. 9). Materials are issued from a concentration store to feed the several sub-assembly sections. One of the most extensive of these is the register section, of which a part is shown in Fig. 10. Every operator is provided with an inspection lamp fitted with a large magnifying glass to facilitate the various checks to which the registers are subjected.

Another large section is that for the brake-magnet assembly, a local view of which is given in Fig. 11. Here the unmagnetised units are assembled in pairs with the aid of a fixture locating the disc gap relative to the dowel pins, and they are then

Fig. 12. *Standardizing magnet strength after magnetising and ageing*

Fig. 13. *Testing potential coils for short-circuits, resistance and turns*

placed individually as paired units on the magnetiser and flashed to saturation level. After heat and time ageing, the magnet pairs are demagnetised to normal working strength (Fig. 12) and are ready for assembling into meters.

The production of potential coils is treated as a sub-assembly. Automatic coil winding machines are employed which feed-in paper between each layer of turns. After finishing, and checking with the apparatus shown in Fig. 13 for short-circuits, resistance value and the number of turns, the coils are sent to the electro-magnet assembly section previously mentioned. Straightening rotor discs, the steam cleaning of jewels and fixing cover glasses are also all treated as sub-assembly operations.

From the sub-assembly concentration stores the various sub-assemblies are fed into main assembly lines (Fig. 9). Each sub-assembly is added in turn to the base assembly as it is passed along slides from operator to operator until completed and inspected. The electro-magnet is first connected and assembled with the main frame ; the bearings and rotor are

Fig. 14. *Stroboscopic calibration of meters*

Fig. 15. *Test boards for final calibration*

then added and finally the brake magnets and register are positioned.

After inspection, the meters are passed into the test room where they are first given insulation and resistance tests, including a high voltage check of 2,000 volts for one minute. The first stage in the calibration is to compare and adjust the newly produced meter with a rotating sub-standard, using stroboscopic speed matching technique for which the apparatus is shown in Fig. 14. The periphery of the disc is used for this purpose, having 400 serrations to ensure a high degree of accuracy. The individual meters are adjusted while undergoing this test to obtain the required standard of accuracy at full load current both with unity power factor and on inductive loads, and ensuring that the British Standard requirements concerning inherent range of adjustment are complied with. After leaving the stroboscopes the meters are stocked in bins appropriate to their type and capacity.

Meters drawn from stock to meet order requirements are set up on test boards each capable of accommodating sixty meters (Fig. 15), and on these the final calibration takes place by direct comparison of the speed at various loads with similar rotating sub-standards. A control panel adjacent to each test board enables the tester to adjust the whole circuit to the required current, voltage and power factor. The potential coils of the meters are energised several hours prior to testing to enable them to attain their normal working temperature. All calibrations are finally re-checked and recorded. Sub-standards are checked at regular intervals with the standardizing equipment maintained in the laboratory (Fig. 16). All calibration is referred to a normal ambient temperature of 20° C. except in the case of meters for certain countries overseas where the normal ambient temperature may be different.

The meters then pass direct to the despatch benches (Fig. 17) for the addition of serial numbers

Fig. 16. *Standardizing sub-standards in the laboratory*

Fig. 17. *Final inspection and despatch of meters*

Fig. 18. *Road transport meter container*

and purchasers' name-plates. If for overseas, the meters are packed in cartons and wooden cases ; if for delivery to testing stations in this country they are despatched in road transport containers (Fig. 18) specially designed to minimise road vibration and to provide easy handling at their destination.

Throughout the whole series of processes involved in meter and instrument manufacture, of which some aspects have been mentioned herein, the objective is the highest possible economic level of production with the minimum wastage of vital materials. Inspection of components at all stages ensures that their quality is controlled and maintained. As a result of the methods employed, it has been possible to achieve the quantity manufacture of products having extremely high precision and which will maintain their accuracy over very long periods.